ALGOMA SLIP SEDIMENT QUALITY

AND

BENTHIC INVERTEBRATE

COMMUNITY ASSESSMENT

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ALGOMA SLIP SEDIMENT QUALITY AND BENTHIC INVERTEBRATE COMMUNITY ASSESSMENT

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Executive Summary

In 1990, the Ontario Ministry of the Environment (MOE) conducted a sediment contamination assessment of the Algoma Slip, located in the upper St. Marys River at Sault Ste. Marie, Ontario. This was a follow-up to sediment contamination and toxicity problems identified by previous Ministry studies (MOE, 1992). The 1990 study involved the collection of sediment cores at 18 stations to determine sediment quality, the degree of impairment of the resident sediment-dwelling invertebrate community, and the toxicity of sediments to organisms in laboratory bioassays. Samples were collected by contract divers supplied by Integrated Explorations, after an initial reconnaissance to determine the depth and characteristics of sediments in the slip. Tarandus Associates Limited was subsequently contracted by the MOE to identify and enumerate the benthic invertebrates in the sediment samples, to summarize and interpret this benthic data, and to examine relationships between the benthic invertebrate community and various environmental (sediment quality) factors.

Sediments collected from the 16 stations located within the slip contained elevated levels of organic carbon, solvent extractables, several inorganics including heavy metals, and also of polycyclic aromatic hydrocarbon (PAH) compounds. Concentrations of arsenic, chromium, copper, iron, manganese, nickel and zinc exceeded the respective Provincial Sediment Quality Guideline (PSQG) Lowest Effect Levels (LELs) at the majority of stations sampled in the slip. Levels of cyanide and solvent extractables (oils and greases) also exceeded the guideline for open water disposal of dredged material at most stations. Concentrations of metals were generally higher at stations located in the middle and eastern portions of the slip. Only manganese and iron exceeded their respective PSQG-Severe Effect Levels (SELs) at a few stations. Levels of total PAHs as well as of 12 individual PAH compounds within the slip also exceeded their respective PSQG-LELs. Sediments from five stations in the western (upper) end of the slip were characterized by much higher concentrations of PAHs than those collected at other sites. In fact, concentrations of total PAHs as well as of eight individual PAH compounds (anthracene, benzo(g,h,i)perylene, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluorene, phenanthrene and pyrene) also exceeded their respective PSQG-SELs at one or more of these stations from the upper end of the slip.

Laboratory sediment bioassays using chironomid larvae, burrowing mayfly nymphs, and juvenile fathead minnows were completed on sediments from six of the 18 stations sampled. The results indicated that sediments from four stations in the western end of the slip were extremely toxic, with mortalities of up to 100%. Sediment from a station in the middle of the slip was not as toxic as those from other stations within the slip, as indicated by mayfly and fathead minnow mortalities of 23 and 4 percent, respectively. Sediment from the upstream control station located in Point Aux Pins Bay was not very toxic, producing mortalities only slightly higher than the reference control sediment from Honey Harbour.

In total, 25 benthic invertebrate taxa (excluding immature tubificids) were identified in sediment cores collected from the 18 stations. All taxa, with the exception of the chironomid *Apsectrotanypus,* have been found during previous studies of the St. Marys River. The number of taxa found at each station was quite variable, ranging from zero at several sites within the slip to a high of 12 at a station just outside the slip. Sediments at six of the stations within the slip were devoid of benthic invertebrates, and at another six sites, only one taxon was found at each. Sediments at two stations in the western end of the slip had unexpectedly high numbers of taxa, given their location at the western end of the slip. This may be due to invertebrate drift from East Davignon Creek or Bennett Creek, tributaries to this end of the slip.

Pollution-intolerant invertebrates such as the burrowing mayfly, *Hexagenia*, were only found at the station just outside the slip and at the upstream control. The absence of mayflies from all stations in and near the Algoma Slip reflects the toxic nature of the sediments at these locations. Sediments within the slip were of such poor quality that even pollution-tolerant invertebrates such as certain tubificids were either absent or occurred in very low numbers.

The volume of sediments in the Algoma Slip was determined to be approximately 14,340 m^3. The greatest accumulations of sediment were, however, located in the upper (western) half of the slip, near the mouths of Bennett and East Davignon Creeks. At some locations in this area, the depth of sediments exceeded 1.75 metres. This area of the slip contained about 29 % of the total volume of sediment in the slip. Sediments from the upper end of the slip were also the most obviously contaminated with oil and coal tar, contained the highest concentrations of polycyclic aromatic hydrocarbons (PAHs), and proved to be highly toxic to laboratory test organisms. The weights of oils and greases and of total PAHs associated with sediments in the upper end of the slip alone are about 10.1 tonnes and 2.3 tonnes, respectively.

A data report (Kauss, 1992) containing a summary and brief interpretation of available data and conclusions was provided to the Ministry's Sault Ste. Marie District Office in June, 1992 to assist in negotiations with Algoma Steel Corp. regarding planned dredging of the slip; it was also used in negotiations related to Algoma Steel's environmental Letter of Agreement. The present document contains a more detailed discussion of the benthic invertebrate community information and an interpretation of communities relative to sediment quality. It also includes additional PAH data not available for the original data report.

Based on data from this and other Ministry studies, the Cleanup and Restoration Task Team of the St. Marys River Remedial Action Plan has identified and prioritized a number of areas of contaminated sediments to be considered for remediation and monitoring; the Algoma Slip ranked the highest in priority. The Algoma Slip is scheduled for maintenance dredging in the summer of 1995.

Acknowledgements

P. Kauss is grateful to the following Ministry personnel for their assistance in carrying out this this study: Richard Harber, captain of the Monitor VI; crew chief Wendy Page and James Reilly and Kevin Becker for field measurements and the processing of sediment samples; staff of the Laboratory Services Branch Inorganic Trace Contaminants and Trace Organics Sections for chemical analysis of the sediment samples; Donna Bedard and Steve Petro of the Watershed Management Section for completion of the sediment bioassays; and Assunta Freda for the calculation of sediment volume. Preliminary surveillance of the Algoma Slip and subsequent collection of sediment cores was carried out by Integrated Explorations, under contract A14025. The identification and enumeration of benthic invertebrate samples, statistical analysis of the benthic data relative to sediment quality, and the production of the majority of this report were performed by Tarandus Associates Ltd., under contract A22158. The draft Tarandus report was reviewed by Todd Howell of the Surface Water Section (SWS). The final report was reviewed by Rein Jaagumagi, also of the SWS, as well as by Gerry LaHaye and Rod Stewart, both of the Sault Ste. Marie District Office. Their suggestions and comments are sincerely appreciated.

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1.0 Introduction

Contaminant inputs from Algoma Steel, as well as from other local industries such as Domtar and St. Marys Paper, and from municipal discharges and overflows, led to the classification of the river as an Area of Concern (AoC) by the International Joint Commission (IJC, 1985). The industrial waste discharge flow rates from Sault Ste. Marie, Ontario, totalled approximately 5.9 $m^3.s^{-1}$ in 1986, with about 95% of this from Algoma Steel (MOE, 1992).

Algoma Steel produces iron and steel from coal (coke), limestone, iron pellets and scrap by using coke ovens, blast furnaces, cupola, and rolling mills (MOE, 1991). Effluent from the mill is known to contain suspended solids (coal, coke, iron) and coal-tar compounds (ammonia, cyanide, oil and grease, phenols) (MOE, 1991). Effluent is discharged continuously from six major outfalls, following treatment which consists of clarifiers, settling basins, brill skimmers, ammonia-recovery stills, biological and physical-chemical treatment processes. The average daily volume of effluent discharged from Algoma Steel in 1989 was estimated at 456,227 $m^3.d^{-1}$ (MOE, 1991). Levels of suspended solids and solvent extractables exceeded acceptable maxima in the Terminal Basins discharge (the company's largest) on eleven and seven occasions, respectively, during 1989 (MOE, 1991). However, these exceedences did not actually constitute violations of the provincial Algoma Steel Control Order, since the Control Order requires that effluent levels be below certain values 90% of the time.

The Algoma Slip is located adjacent to the Algoma Steel Corporation on the St. Marys River, upstream of the St. Marys Falls at Sault Ste. Marie, Ontario (Figure 1). The slip serves as a docking area for large commercial vessels and also receives contaminant inputs from three Algoma Steel Corp. discharges (30" and 60" blast furnace sewers, plus the 24" coke quench overflow) and from two tributary creeks (East Davignon and Bennett).

Algoma Steel is a documented source of several contaminants to the river, including polycyclic aromatic hydrocarbons (PAHs) (Kauss and Hamdy, 1991), iron, oils, phenols and cyanide (MOE, 1992). Elevated concentration of PAHs are frequently associated with the sediments below steel and/or coke industries (Murphy *et al.*, 1991; NRTC, 1984; Pope *et al.*, 1992; Pope, 1993). Investigations at the Algoma Steel slag dump, located on the south shore of the slip, also found PAHs in groundwater under the site (Berry-Spark and Tossell, 1990). PAHs are of particular concern because of their low water solubility, a property which promotes adsorption onto particulate matter and subsequent deposition in sediments. Consequently, aquatic organisms such as benthic invertebrates may be exposed to elevated levels of PAHs, a situation which may result in the accumulation of PAHs in the lipid fraction of the animals.

Analysis of 1987 surficial sediment samples from two stations within the slip and two at the mouth showed the presence of high concentrations of metals, oil and grease and PAHs (MOE, unpubl. data). Over the years, spills have contaminated Bennett Creek with coal tar which contains very high concentrations of unsubstituted and substituted polycyclic aromatic hydrocarbons (MOE, unpubl. data). A diver survey conducted for Algoma Steel Corp. in 1988 did not find any pools of 'free' coal tar in Algoma Slip sediments. Nevertheless, both Bennett Creek sediment as well as silty deposits in the slip near the Bennett Creek discharges contained minute black specks that caused iridescence when the sediments were disturbed (Conestoga-Rovers and Associates, 1988). This, combined with elevated surficial sediment PAH levels, suggests that PAHs had reached the slip relatively recently. Furthermore, the elevated concentrations of both metals and PAHs outside the eastern mouth of the Algoma Slip suggests that contaminated sediments can move out of the slip, thereby being available for transport and subsequent contamination of downstream areas of the river.

Previous surveys of benthic invertebrate communities in the St. Marys River have revealed several zones of impairment, especially downstream of discharges from Algoma Steel, St. Marys Paper, and the Sault Ste. Marie East End Water Pollution Control Plant (WPCP) (Veal, 1968; McKee *et al.*, 1984; Burt *et al.*, 1988; Pope, 1990). In 1985, the benthic macroinvertebrate community of the Algoma Slip was severely impacted, being comprised mainly of organic pollution-tolerant tubificids and nematodes (Burt *et al.*, 1988).

In 1990, the Ontario Ministry of the Environment (MOE) conducted a detailed follow-up sediment contamination assessment of the Algoma Slip (Kauss, 1990). This involved the collection of sediments to determine sediment quality, the degree of impairment of the resident benthic invertebrate community and the toxicity of these sediments in laboratory bioassays. Samples were collected by contract divers, supplied by Integrated Explorations, after an initial reconnaissance to determine the depth and characteristics of sediments in the slip (Integrated Explorations, 1990). Tarandus Associates Limited was contracted by the MOE to identify and enumerate benthic meio- and macroinvertebrates from the sediment samples and to summarize and interpret the benthic data and examine relationships between the benthic community and various environmental i.e., sediment quality, factors (Pope, 1993).

The overall objectives of the study were:

1) to obtain more detailed information on the magnitude and extent of sediment contamination in the Algoma Slip and its impact on resident benthic biota as well as on downstream areas.

2) to determine the limiting factors on improvement of the benthic invertebrate community in the slip.

3) to provide recommendations for remediation, if warranted.

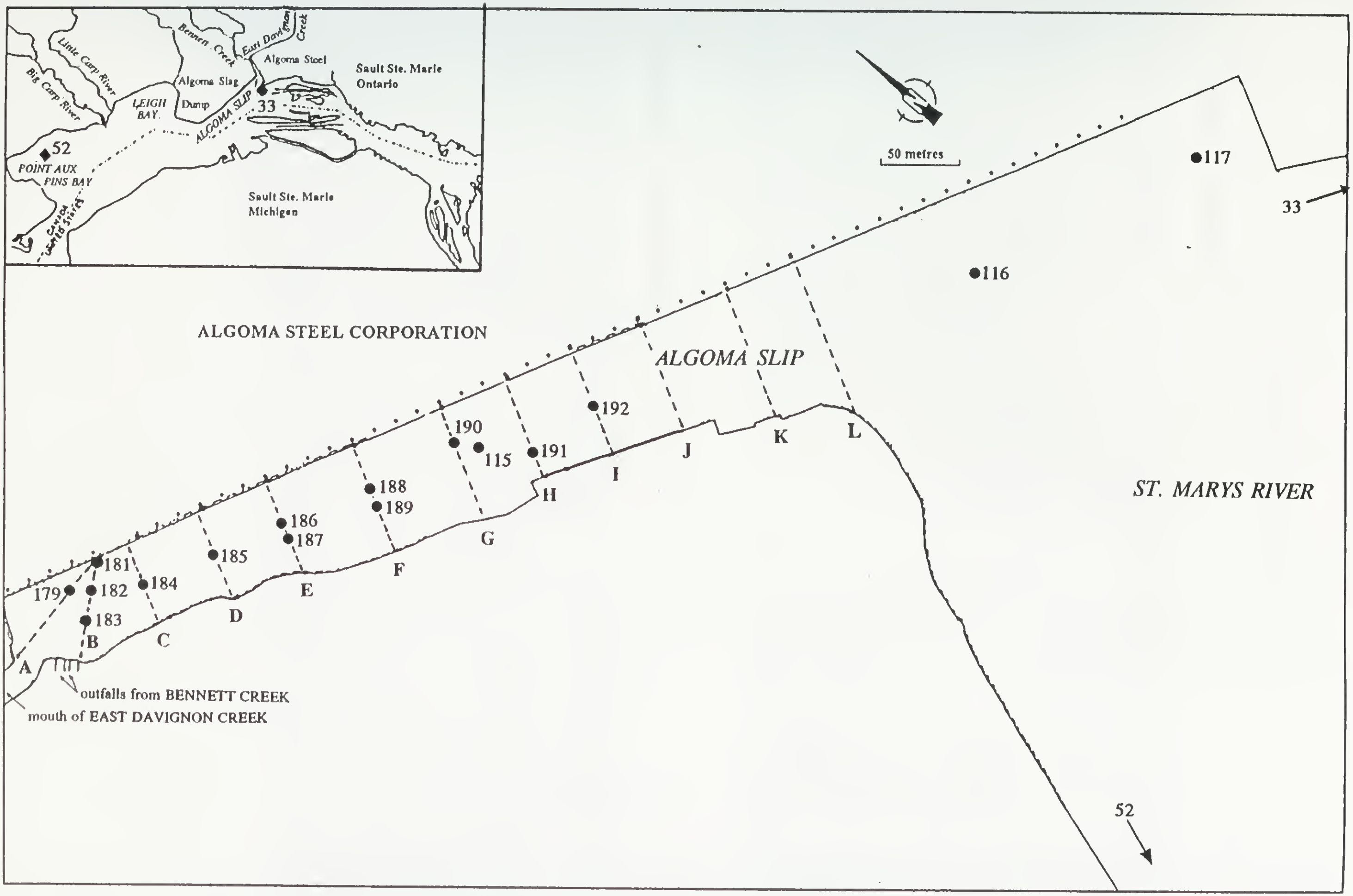

Figure 1: **Sampling locations in the Algoma Slip and the St. Marys River.** The location of the preliminary surveillance transects is indicated by dashed lines and letters (see also Appendix I).

2.0 Study Methods

2.1 Preliminary Surveillance

Before collecting any samples, preliminary surveillance was conducted by a diver operating from the MOE vessel Monitor VI to identify areas of sediment deposits and their composition. Between August 27 and August 29, the diver anchored 12 polypropylene transect survey lines (marked at 1 metre increments) across the bottom of the Algoma Slip at discrete intervals (Figure 1). The diver then moved along each of the survey lines and, at 10 metre intervals, provided a visual description of the bottom to the surface crew by two-way radio. The presence or absence of oils and coal tar was also investigated by pushing a special 50 cm long by 5 cm wide, flat, plastic probe into the sediment at each 10 m interval. This white plastic probe, developed by Integrated Explorations, has an affinity for oils and tars. Contact with coal tar results in a brown discolouration of the probe; oil causes a black smudge. Clay, which also clings to the probe, can easily be wiped off, while coal tar and oil cannot. This 'probe' method permitted the detection of oily contaminants buried in the sediments on a semi-continuous basis, thereby providing information on the spatial distribution of oil and/or coal tar contamination. The plastic probes were returned to the survey vessel by the diver after completion of each transect, photographed, and the visual and olfactory observations recorded (Integrated Explorations, 1990). The diver's observations of sediment characteristics are summarized in Appendix I.

2.2 Sediment Core Collection and Field Processing

Once sites of sediment contamination had been identified, sediment cores were collected by diver from 16 stations within the Algoma Slip, one station just outside the mouth of the slip, and an upstream control station in Point aux Pins (Marks) Bay (Figure 1). All sampling occurred between August 29 and September 1, 1990. At each station, a minimum of three cores were obtained by the diver pushing 13.65 cm I.D. clear acrylic plastic tubes to their maximum depth (i.e., to hardpan or refusal). The cores were capped at each end and then brought to the surface, and the length of the sediment core was determined on the survey vessel (to the nearest mm) and any obvious vertical zonation recorded. Due to the nature of the substrate, the length of sediment cores varied among stations, ranging from 110 mm to 432 mm. A summary of the station locations, the length of each replicate core, and the visual and olfactory characteristics is presented in Appendix II. The replicate cores from each station were each extruded into individual solvent (hexane)-rinsed stainless steel pans, and thoroughly homogenized with a clean stainless steel spoon by Ministry staff. To maximize the subsequent utility and correlation of data, this homogenate served as the source of sediment chemistry, benthic invertebrate and sediment bioassay samples.

2.2.1 Sediment Chemistry

A small aliquot of the sediment homogenate was weighed in a container of known volume to obtain the field (wet) weight and field density. Sediment chemistry samples were placed in the prescribed jars (MOE, 1989) and submitted for chemical analysis to the Ministry's Laboratory Services Branch in Etobicoke, Ontario. Analyses included particle size distribution, moisture content, total organic carbon, loss on ignition, arsenic, cyanide, heavy metals, solvent extractables (oils and greases) and infrared specroscopy, and 16 unsubstituted polycyclic aromatic hydrocarbons (PAHs). A single sample obtained by compositing and homogenizing material from the three replicate cores was submitted for most stations; however, the three replicates from stations 179, 181, 182 and 190 were individually analyzed. For stations 183 and 52, the three replicates were each split into two in the field, thereby resulting in six samples for each of these two stations. All chemical analyses were conducted according to documented methods (MOE, 1983 and updates).

2.2.2 Benthic Invertebrates

Three replicate benthic invertebrate samples were obtained from each station, with the exception of stations 52 and 183, where the three replicates were each split in two to yield a total of six samples. Each benthos sample was obtained by washing 1.5 litres of the homogenized, wet sediment from each core through a 200 μm Nitex bag to retain meio- and macroinvertebrates. The filtrate was then transferred to a labelled glass jar and preserved with buffered (pH$\approx$7), 5% formalin.

2.2.3 Sediment Bioassays

For stations 179, 181, 182, 183, 190, and 52, the remaining two to three litres of homogenized sediment from each replicate were transferred into a food-grade polyethylene bag and shipped in plastic pails to the MOE Bioassessment Laboratory in Etobicoke. The samples were kept refrigerated at $\sim$4 °C until they were used in acute and chronic sediment bioassays (see section 2.5).

2.3 Water Physical and Chemical Measurements

Current velocity was measured with a Marsh-McBirney meter at each of the 18 stations, at three depths: 0.5 m below surface, mid-depth, and 0.15 m above the sediment surface. Water temperature, conductivity , pH and dissolved oxygen were also measured at these three depths, using meters calibrated at the beginning of each day.

2.4 Invertebrate Identification and Enumeration

A total of 57 benthos samples were examined. Each sample was manually washed, picked, and sorted to separate all organisms from associated debris. All samples were picked in their entirety by Ms. Margaret Pickles and processed with the use of a stereomicroscope at 10X magnification. Small quantities of sample were placed in a grid-lined petri dish and scanned for organisms. Upon completion of the preliminary scanning, the sample was agitated and re-scanned a second time to ensure that no organisms were overlooked. Organisms found in each sample were initially sorted into similar ordinal groups, with the exception of chironomids which were separated from any other Diptera, and placed in separate labelled vials for subsequent identification. Sample sorting required on average 2 to 2.5 hours per sample. Samples containing large amounts of debris were elutriated by the use of methods described by Barton *et al.* (1988, 1989). Approximately 200-300 ml of sample was placed into the elutriating tube with warm water and air flowing into the bottom of the tube. Total elutriation time for each sample was approximately 1 to 1.5 hours.

All benthic invertebrates were identified to the lowest practical taxonomic level by Mr. Brad Hubley and Mr. Don Stacey of Original Insect Ideas. Details regarding the qualifications of Mr. Hubley, Mr. Stacey, and Ms. Pickles are presented in Appendix III. Prior to identification, tubificids and chironomids were cleared and mounted on labelled microscope slides. Oligochaetes were mounted in CMCP-9 and allowed to dry for 3-4 days to provided sufficient clearing for subsequent examination under a compound microscope. Chironomids were mounted in a mixture of CMCP-9 and CMCP-9-AF (CMCP-9 with acid fuschin stain) at a ratio of approximately 3:1 and allowed to dry for 3-4 days before examination under a compound microscope. The remaining organisms were examined under a dissecting microscope for identification to the lowest practical level, and then placed in labelled vials containing 70% ethanol. Table 1 presents the levels of identification for specific groups of benthic invertebrates. Taxonomic references used for invertebrate identification are listed on page 41.

After completion of analysis, all sorted invertebrate samples were delivered to the MOE contract liaison officer (P. Kauss) on slides or in vials, each labelled with the species identification, date, station, and total core length.

2.5 Laboratory Sediment Bioassays

After screening through a 2,000 μm polyethylene sieve to remove existing large biota and debris, the sediment samples from stations 179, 181, 182, 183, 190, and 52, as well as background sediment from Honey Harbour, Ontario were used in static laboratory tests (Bedard and Petro, 1992) to evaluate sediment toxicity and the bioavailability of selected contaminants. The tests involved a 21 day lethality and growth assay with burrowing mayfly nymphs (*Hexagenia limbata*), an 11 day lethality and growth assay with midge larvae (*Chironomus tentans*), and a 21 day lethality and bioaccumulation assay with juvenile fathead minnows (*Pimephales* *promelas*). All bioassays were conducted according to documented testing protocols (Bedard *et al.*, 1992).

Table 1: Levels of identification for specific groups of benthic ivertebrates.

Invertebrate Group	Level of Identification
DIPTERA	
Ceratopogonidae	Genus
Chironominae	Genus
Orthocladiinae	Genus
Tanypodinae	Genus
EPHEMEROPTERA	
Ephemeridae	Genus
GASTROPODA	
Physidae	Species
Valvatidae	Genus
PELECYPODA	
Sphaeriidae	Genus
AMPHIPODA	
Gammaridae	Genus
ISOPODA	
Asellidae	Genus
OLIGOCHAETA	
Tubificidae	Species
Naidiae	Species

2.6 Data Analysis

2.6.1. Diversity Index

The use of indices provides a simple method of summarizing complex benthos data. Indices can be described as derived variables such as a ratio of one variable divided by a standard variable. When applied to invertebrate data, such indices generally involve ratios of numbers of taxa and numbers of individuals in collected samples, and have interpretive value as data summaries.

The Shannon-Weaver (or Shannon-Weiner) Diversity Index (H') is a measure of the distribution of observations among categories (e.g. species). When applied to communities of invertebrates, diversity calculations incorporate the counts of organisms within each taxonomic group. A low diversity is the result of a concentration of invertebrates in few categories; and conversely, a more uniform distribution of organisms among all categories results in a high diversity. The index also provides some information on the richness of categories. The formula for the Shannon-Weaver diversity index, H' is:

$$H' = -\sum_{i=1}^{s} \frac{N_i}{n} \log_2 \frac{N_i}{n}$$

$$= -1.447 \sum_{i=1}^{s} \frac{N_i}{n} \ln \frac{N_i}{n}$$

where n = the total number of individuals in the sample
N_i = the number of individuals in the "i"th sample

Diversity indices were calculated using Statistical Ecology basic software (Ludwig and Reynolds, 1988). The indices presented in this report provide some useful information, however they should be interpreted with some caution given the presence of few individuals and the sampling strategy used.

2.6.2. Comparison with Provincial Sediment Quality Guidelines

Concentrations of selected sediment quality parameters were compared to the Provincial Aquatic Sediment Quality Guidelines (PSQGs) (Persaud *et al.*, 1993). These guidelines were developed to replace the Open Water Disposal Guidelines (OWDGs) (Persaud and Wilkins, 1976) which were originally intended for use in assessing the suitability of soils and dredged material for open-water disposal. The PSQGs are specifically intended to protect aquatic biological resources by setting safe levels for metals, nutrients, and organic compounds. These guidelines are based on three levels of ecotoxic effects: a no-effect level (NOEL), a lowest effect level (LEL), and a severe effect level (SEL), the significance of which are summarized in Table 2.

Concentrations of selected sediment quality parameters were also illustrated using Fig.P graphics software (Fig.P, 1990). In the cases of stations with replicate chemical analyses, all means were calculated arithmetically.

2.6.3 Principal Components Analysis

Principal Components Analysis (PCA) was used to analyze the patterns of variability in the sediment quality results. PCA is a technique for deriving linear combinations of the original

Table 2: **Provincial Sediment Quality Guidelines and their significance** (Persaud *et al.*, 1993).

Contaminant Concentration	Sediment Quality	Potential Impact
≥ Severe Effect Level	grossly polluted	will significantly affect use of sediment by the majority of benthic organisms
≥ Lowest Effect Level	marginally to significantly polluted	will affect sediment use by some (sensitive) benthic organisms
≥ No Effect Level	clean to marginally polluted	potential to affect some sensitive water uses
≤ No Effect Level	clean	expect no impact on benthic organisms or biomagnification through the food chain; other water quality and use guidelines will be met

variables, called principal components, that are orthogonal to one another and that successively account for the largest portion of the residual variance (Rogers, 1971). This method, as with most multivariate statistical techniques that reduce the dimensionality of multivariate observations, is used to generate a smaller number of variables which summarize most of the information contained in the original variables. PCAs were calculated on the correlation matrices of sediment parameters. The data were rank-transformed prior to the calculation of the correlation matrices.

The "factor loadings" produced by PCA are the correlation coefficients between each original variable and each principal component. The first two factors were graphed for presentation in this report. Sediment physical and chemical quality parameters used in the PCA included: percent silt and clay, percent very fine to coarse sand, percent very coarse sand, as well as concentrations of inorganics and metals, total organic carbon (TOC), loss on ignition (LOI), solvent extractables, and of 16 PAH compounds. PAH data were not available for stations 185, 186 and 117 and therefore these sites were excluded from the analysis.

The PCAs were calculated with the use of SYSTAT computer software (Wilkinson, 1990) and the results were presented graphically with the use of the associated SYGRAPH package (Wilkinson, 1990).

3.0 Results and Discussion

3.1 Sediment Characteristics

In contrast to the fine silty-sand sediment from the control station in Point aux Pins Bay, Algoma Slip sediments tended to be more sandy (gritty) in nature, at times also including gravel, coal or other debris (Appendix I). Laboratory analysis showed that sediments from stations in the Algoma Slip consisted mostly of very fine to coarse sand and 'fines' (silt and clay, Table 4).

The percentages of fines were generally higher at stations towards the eastern end of the slip and at station 52 in Point Aux Pins Bay, than at other sites (Figure 2). Overall, the deepest sediment deposits were found in the western half of the slip, near the East Davignon and Bennett Creek discharges. Along Transects A to F, sediment depth ranged from 0.10 to more than 1.75 metres (Appendix I). Transects A to F also appeared to be the most contaminated: the plastic sediment probes from 32 of the 40 locations examined by the diver from these six transects were streaked brown-black or black (Appendix I), indicating the presence of coal tar and/or oil; some of the probes also smelled of coal tar. Core sediment samples from six of the 16 slip stations later sampled also smelled of coal tar (Appendix II). Microscopy and X-Ray diffraction revealed that, for the eight samples from the slip submitted for this analysis, ~50% to ~70% of the sediment particles were composed of coke, coal and coal soot particles, with decreasing contributions from detrital mat, slags, wood chips and fibres, and plant fibres (Table 3).

Diffuse reflectance Fourier transform infrared spectroscopy of sediment extracts from the solvent extractables analysis revealed the presence of humic acids at all stations, but coal tars were restricted to the Algoma Slip stations (Table 3). Lanolin (wood fat) was only found at the control station 52 and in sediments from stations 116, 117 and 33, near or outside the mouth of the slip.

3.2 Sediment Quality

High levels of total organic carbon (TOC) and of loss on ignition were usually found at stations in the middle of the slip (stations 181, 185, 186, 187, 188, 189, 190. 115, 191, and 192) (Figure 2; Table 4). TOC exceeded the PSQG-LEL of 10 $mg.g^{-1}$ at all stations except control station 52, and exceeded the PSQG-SEL of 100 $mg.g^{-1}$ at stations 179, 181, 185, 186, 187, 188, 189, 190. 115, 191, and 192 (Table 4). Concentrations of solvent extractables exceeded the Open Water Disposal Guideline (OWDG) of 1,500 $\mu g.g^{-1}$ at all stations except 116, 117, 33, and 52 (Table 4). The highest levels of solvent extractables were found in sediments from stations 179, 181, 185, 186 and 115, where concentrations ranged between 8,021 and 10,084 $\mu g.g^{-1}$.

Overall, sediments within the slip were "marginally" to "grossly polluted" with respect to the concentrations of arsenic, heavy metals and PAHs (Persaud *et al.*, 1993). With the exception of mercury, the levels of all inorganics and metals exceeded their respective PSQG-LELs at

Table 3: Microscopic and spectrometric characteristics of sediment core samples.

Station:	Microscopy/XRD							DRFT-IR Spectrometry		
	Coke, Coal & Coal Soot	Detrital Mat	Magnetic &/or Glassy Slags	Tar Debris	Wood Chips & Fibres	Plant Chips	Biological Mat	Humic Acids	Lanolin (Wood Fat)	Coal Tars
179	~ 70%	~ 20%	~ 10%	trace	--	--	--	√	--	√
183	na	na	na	na	na	na	na	√	--	√
182	~ 70%	~ 20%	~ 10%	--	trace	trace	--	√	--	√
181	~ 60%	~ 30%	~ 10%	--	trace	--	--	√	--	√
184	~ 50%	~ 40%	~ 10%	--	--	trace	--	√	--	√
185	na	na	na	na	na	na	na	√	--	√
186	na	na	na	na	na	na	na	√	--	√
187	~ 60%	~ 30%	~ 10%	--	trace	--	trace	√	--	√
188	~ 70%	~ 20%	~ 10%	--	trace	trace	--	√	--	√
189	na	na	na	na	na	na	na	√	--	√
190	~ 60%	~ 20%	~ 20%	--	--	trace	--	√	--	√
115	na	na	na	na	na	na	na	√	--	√
191	na	na	na	na	na	na	na	√	--	√
192	~ 50%	~ 30%	~ 20%	--	trace	trace	--	√	--	√
116	na	na	na	na	na	na	na	√	√	√
117	na	na	na	na	na	na	na	√	√	√
33	na	na	na	na	na	na	na	√	√	--
52	na	na	na	na	na	na	na	√	√	--

NOTES:

Microscopy/XRD = stereo, polarized and electron microscopy / X-ray diffraction.
DRFT-IR = diffuse reflectance Fourier transform infrared spectroscopy.
'√' = present.
'--' = not present or reported.
'na' = no data available.

least one station (Table 5). Contaminant concentrations were considerably lower at the upstream control station than those reported at all the sites within the slip, and concentrations at station 52 did not exceed any PSQGs. The highest concentrations of several parameters including cyanide (1.30 $\mu g.g^{-1}$), cadmium (0.95 $\mu g.g^{-1}$), chromium (58 $\mu g.g^{-1}$), lead (46 $\mu g.g^{-1}$), iron (60,000 $\mu g.g^{-1}$), magnesium (14,000 $\mu g.g^{-1}$), manganese (2,000 $\mu g.g^{-1}$), mercury (0.18 $\mu g.g^{-1}$), nickel (38 $\mu g.g^{-1}$) and zinc (250 $\mu g.g^{-1}$) were found at sites located in the eastern end of the slip, especially at stations 116 and 117 (Figures 3, 4, and 5). Concentrations of iron and manganese at these two stations also exceeded the respective PSQG-SELs (Table 5)). Mudroch (1991) also detected high levels of arsenic, lead, iron and zinc in samples collected by the MOE at the entrance to the Algoma Slip in 1987.

Due to the loss of some sample jars, PAH analyses could not be performed for three of the 18 stations sampled in the Algoma Slip. Nevertheless, the available analytical results summarized in Table 6 indicate some extremely high PAH concentrations in slip sediments. Total PAH levels exceeded the PSQG-LEL of 4 $\mu g.g^{-1}$ at stations 179, 183, 182, 181, 184, 187, 188, 189, 190, 115, 191, 192 and 116 where concentrations ranged from 9.29 $\mu g.g^{-1}$ to 2,470 $\mu g.g^{-1}$. At nine of these 13 stations, concentrations of all 12 of the individual PAH compounds for which guidelines are available were also above their respective PSQG-LELs. The highest levels of PAHs were found in sediments from stations 179, 183, 182, 181 and 184 at the west end of the slip. Concentrations of up eight individual compounds as well as of total PAHs also exceeded their respective PSQG-SELs at many of these five stations. Such contaminant levels have the potential to 'significantly affect use of the sediment by the majority of benthic organisms' (Table 2).

Of the 16 PAHs analyzed for, fluoranthene, phenanthrene and pyrene were found in the highest concentrations. Kauss and Hamdy (1991) also reported higher concentrations of these PAHs in surficial sediments and mussels from most sampling locations in the St. Marys River during 1985. They suggested that high-temperature combustion of fossil fuels, which occurs during the burning of coal or coke manufacturing was the major contributor of these types of PAHs. The concentrations of PAHs in sediments from stations 115, 117, and the upstream control examined by Kauss and Hamdy (1991) are presented in Table 7, as are concentrations at these and other stations in or near the slip from a 1987 MOE study (unpubl. data). Of all the sites evaluated by Kauss and Hamdy (1991) in the St. Marys River, the highest concentrations of total PAHs and of individual PAH compounds were found in the middle of the Algoma Slip (station 115). PAH concentrations found at station 115 during the present study are between the 1985 and 1987 values. Concentrations at station 33, outside the slip, were much lower in 1990 than in 1987. PAH levels at the upstream control station 52 were close to the method reporting values in 1987 and not detected in 1990.

Sediment contamination associated with outfalls from steel and/or coke manufacturers has been found at other locations in the Great Lakes, including Hamilton Harbour (Poulton, 1987; MOE, 1985; Pope, 1993), the Detroit River (Farara and Burt, 1993), the Welland River (Pope, 1992; Acres International Limited, 1990), and the Buffalo River (NRTC, 1984).

Table 4: **Concentrations of total organic carbon, loss on ignition and solvent extractables, and percentages of silt and clay (<62μm diameter), very fine to coarse sand (>62μm to <1,000 μm), and very coarse sand (1,000 μm to 2,000 μm) in sediment samples from the Algoma Slip and Pointe aux Pins Bay.**

Where results are available for replicate samples, the mean and standard deviation are presented. Mean values in completely shaded cells exceed the PSQG-LEL for TOC (10 mg.g^{-1}) or the Open Water Disposal Guideline for oil and grease (1,500 mg.g^{-1}). Bolded and partially shaded means exceed the PSQG-SEL for TOC (100 mg.g^{-1}).

	West <------------------------------- Algoma Slip -------------------------------> East																	Control
Station:	179	183	182	181	184	185	186	187	188	189	190	115	191	192	116	117	33	52
No. Replicates:	3	6[1]	3	3	1	1	1	1	1	1	3	1	1	1	1	1	1	6[1]
Loss on Ignition[2] (mg.g^{-1})	50.0 ± 9.5	58.5 ± 31.8	15.7 ± 4.6	60.7 ± 13.0	31.0	46.0	170.0	98.0	94.0	150.0	90.0 ± 26.0	120.0	78.0	110.0	25.0	45.0	8.9	20.8 ± 6.7
Total Organic Carbon (mg.g^{-1})	**101.3** ± 24.2	75.8 ± 24.8	41.7 ± 3.5	**153.3** ± 5.8	54.0	**130.0**	**230.0**	**200.0**	**270.0**	**330.0**	**146.7** ± 20.8	**310.0**	**210.0**	**360.0**	22.0	59.0	14.0	9.1 ± 3.4
Solvent Extractables (μg.g^{-1})	10084 ± 3364	2775 ± 1052	2895 ± 489	8021 ± 1966	3117	10870	9946	3787	4384	5575	1557 ± 497	9199	3268	4460	1213	588	205	617 ± 177
Very Coarse Sand (%)	13.1 ± 3.2	1.3 ± 0.2	2.1 ± 0.3	3.0 ± 1.9	3.3	4.7	5.6	9.2	2.3	4.3	3.9 ± 2.0	3.1	5.2	3.4	10.2	5.1	5.7	0.3 ± 0.1
Very Fine to Coarse Sand (%)	75.0 ± 0.4	91.0 ± 2.0	91.2 ± 2.3	79.8 ± 3.6	90.0	82.1	76.3	75.7	71.7	70.6	57.7 ± 17.5	71.3	67.9	74.6	27.4	53.5	75.5	31.4 ± 1.4
Silt & Clay (%)	11.8 ± 2.8	7.4 ± 2.1	6.4 ± 1.7	16.7 ± 4.7	6.1	13.1	17.9	15.0	25.8	24.8	38.0 ± 19.0	25.4	26.8	21.8	62.0	41.1	18.6	68.0 ± 1.5
Moisture (%)	25.3 ± 5.9	30.0 ± 1.7	29.0 ± 1.7	36.0 ± 1.0	27.0	33.0	38.0	32.0	37.0	38.0	36.7 ± 2.3	41.0	33.0	42.0	41.0	40.0	21.0	45.7 ± 5.3
Field Density (g.cm^{-3})	1.332 ± 0.076	1.680 ± 0.016	1.618 ± 0.049	1.456 ± 0.067	1.591	1.470	1.357	1.506	1.353	1.310	1.591 ± 0.023	1.409	1.544	1.385	1.655	1.668	2.014	1.586 ± 0.063

NOTES: 1 - Results are for 3 replicates, each split into a blind duplicate.
2 - PSQGs not available for this parameter.

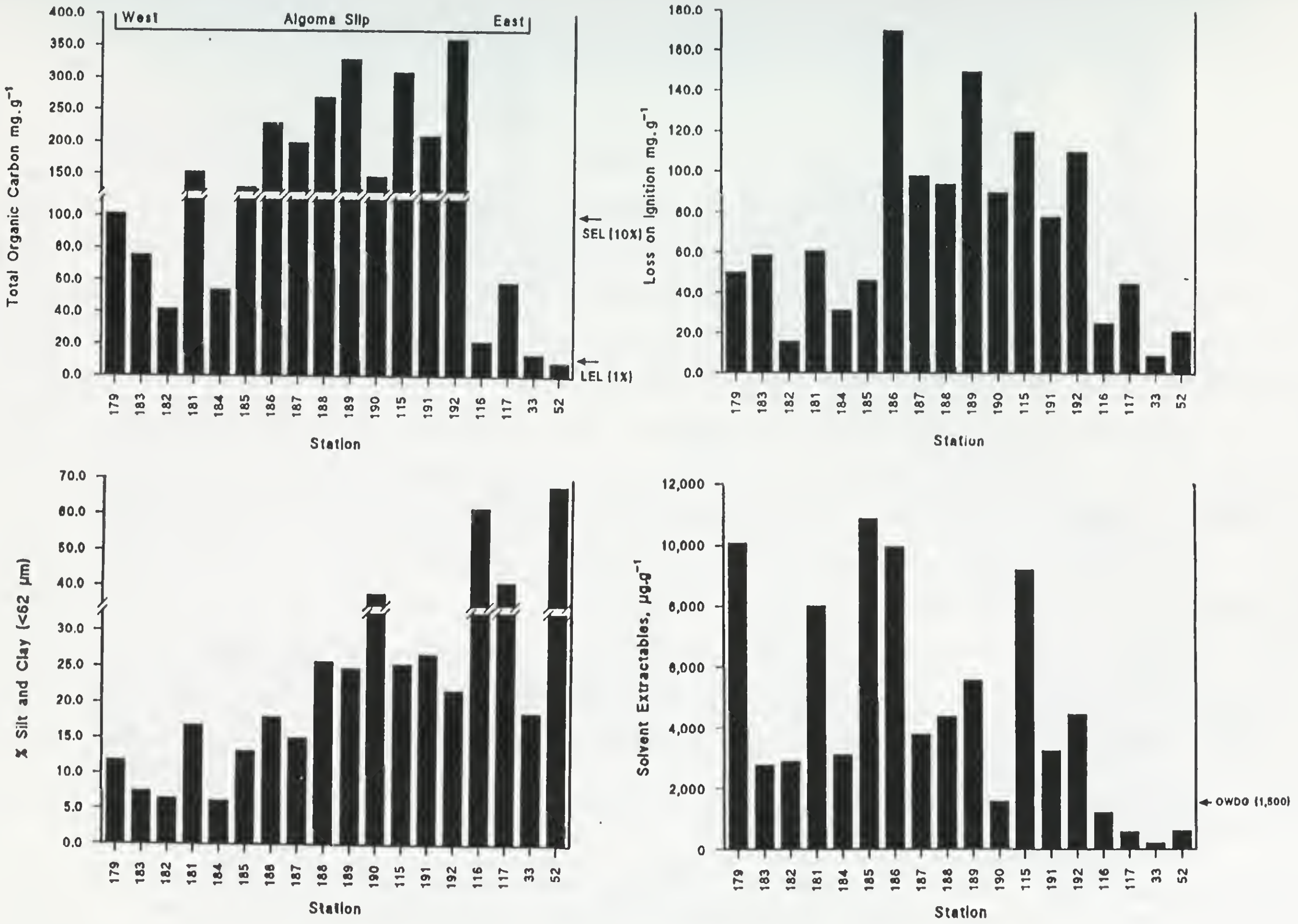

Figure 2: Total organic carbon, loss on ignition, percent silt and clay and solvent extractables in sediment samples from the Algoma Slip and Pointe aux Pins Bay.

Table 5: **Concentrations of inorganics and heavy metals in sediments samples from the Algoma Slip and Pointe aux Pins Bay.** Where results are available for replicate samples, the mean and standard deviation are presented. Mean values in completely shaded cells exceed PSQG-LELs. Means exceeding PSQG-SELs are bolded and only partially shaded. All concentrations are in $\mu g.g^{-1}$ (dry weight).

	West <---------- Algoma Slip ----------> East																	Control
Station:	179	183	182	181	184	185	186	187	188	189	190	115	191	192	116	117	33	52
No. Replicates:	3	6[1]	3	3	1	1	1	1	1	1	3	1	1	1	1	1	1	6[1]
Arsenic	8.1 ± 2.7	6.0 ± 0.6	6.1 ± 0.4	6.8 ± 0.3	9.4	9.2	8.0	11.0	9.7	8.2	7.3 ± 2.2	8.5	9.6	7.8	5.1	9.7	7.1	1.5 ± 0.3
Cyanide[2]	0.45 ± 0.42	0.12 ± 0.06	0.13 ± 0.03	1.03 ± 0.06	0.50	0.15	0.94	0.21	1.5	0.22	0.14 ± 0.04	1.60	0.01	0.01	0.04	1.30	0.05	0.03 ± 0.03
Cadmium	0.31 ± 0.11	0.05<W ± 0.02	0.08 ± 0.02	0.48 ± 0.07	0.35	0.14	0.52	0.65	0.52	0.82	0.56 ± 0.08	0.27	0.39	0.05	0.47	0.95	0.24	0.05<W ± 0.03
Chromium	28.7 ± 2.1	23.5 ± 1.8	21.0 ± 1.0	27.3 ± 2.5	24.0	25.0	27.0	28.0	36.0	35.0	40.7 ± 6.8	33.0	36.0	33.0	58.0	55.0	18.0	14.5 ± 1.3
Copper	19.3 ± 3.2	21.2 ± 10.8	14.7 ± 1.5	42.7 ± 19.1	40.0	22.0	34.0	28.0	29.0	33.0	35.7 ± 3.1	38.0	31.0	29.0	38.0	36.0	11.0	8.7 ± 1.0
Iron	28000 ± 3464	24333 ± 1528	26000 ± 2646	24000 ± 1000	31000	32000	24000	35000	38000	32000	35667 ± 4041	35000	**44000**	37000	**45000**	**60000**	28000	8067 ± 633
Lead	33.7 ± 15.9	16.0 ± 3.9	17.0 ± 5.6	29.0 ± 12.5	23.0	18.0	30.0	27.0	41.0	27.0	22.3 ± 3.8	46.0	32.0	36.0	26.0	41.0	27.0	3.1 ± 2.0
Magnesium[3]	3800 ± 0	3267 ± 318	3067 ± 58	3767 ± 58	3400	9900	4200	4300	4500	4800	8667 ± 3137	5300	5300	5200	14000	9300	2300	2350 ± 312
Manganese	696.7 ± 30.6	645.0 ± 56.3	536.7 ± 30.6	716.7 ± 20.8	620.0	710.0	680.0	820.0	810.0	840.0	776.7 ± 80.2	840.0	950.0	870.0	**1100.0**	**2000.0**	560.0	95.8 ± 9.8
Mercury	0.05 ± 0.01	0.01 ± 0.02	0.06 ± 0.10	0.06 ± 0.05	0.04	0.03	0.04	0.04	0.04	0.04	0.04 ± 0.01	0.09	0.07	0.06	0.18	0.06	0.02	0.01 ± 0.01
Nickel	15.3 ± 3.2	13.5 ± 0.0	15.7 ± 3.8	17.0 ± 0.0	16.0	16.0	17.0	20.0	18.0	21.0	31.3 ± 2.1	19.0	19.0	18.0	38.0	33.0	12.0	9.1 ± 0.7
Zinc	93.3 ± 6.1	71.2 ± 8.5	64.7 ± 6.7	103.3 ± 5.8	74.0	92.0	120.0	140.0	140.0	150.0	130.0 ± 20.0	140.0	150.0	130.0	110.0	250.0	140.0	21.2 ± 2.4

NOTES:
1 - Results are for 3 replicates, each split into a blind duplicate.
2 - PSQGs not yet available for this parameter; exceedences are of the Open Water Disposal Guideline for Dredged Material.
3 - PSQGs not yet available for this metal.
'<W' suffix = no measurable response (zero); less than reported value.

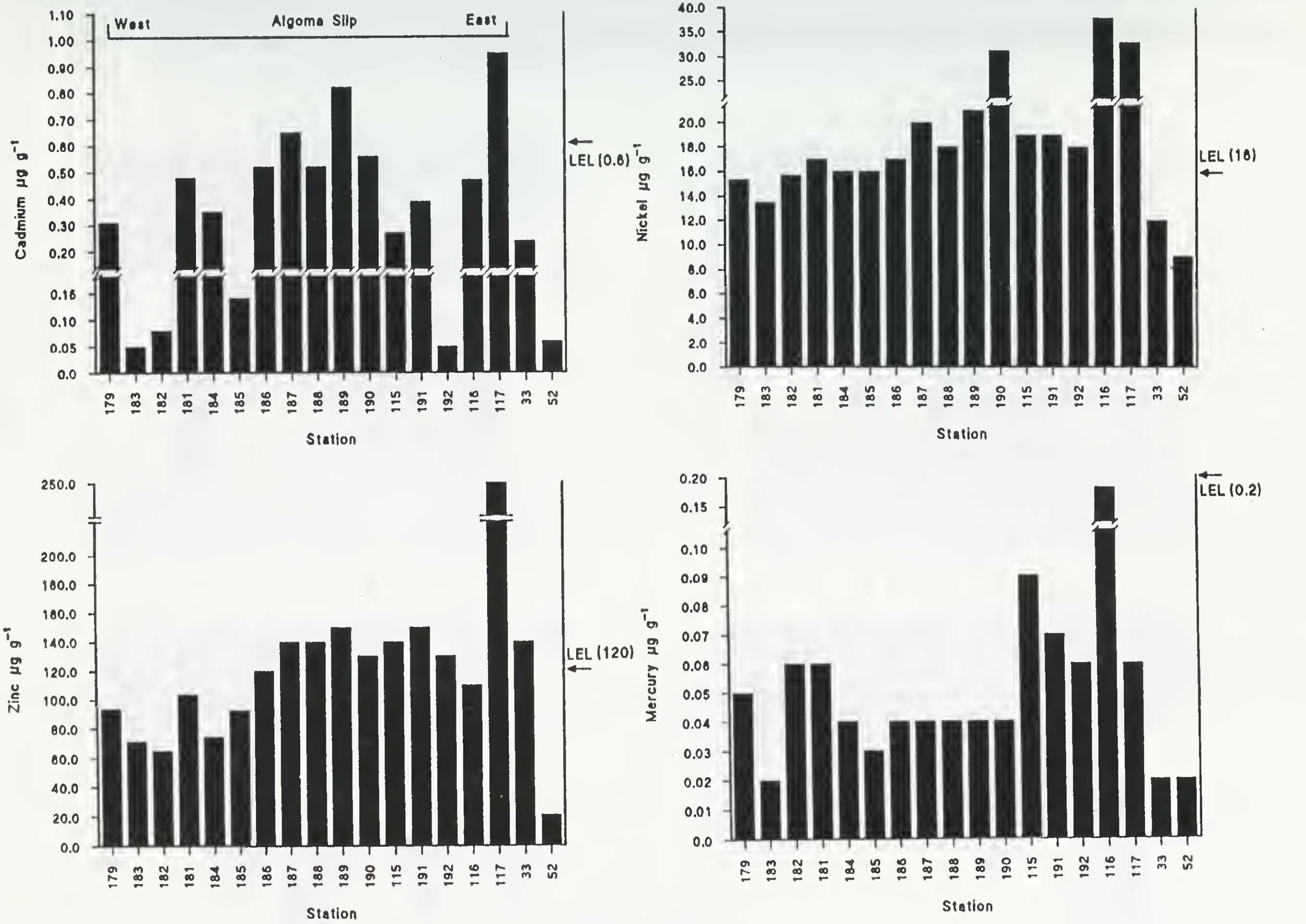

Figure 3: Concentrations of cadmium, nickel, zinc and mercury in sediment samples from the Algoma Slip and Pointe aux Pins Bay.

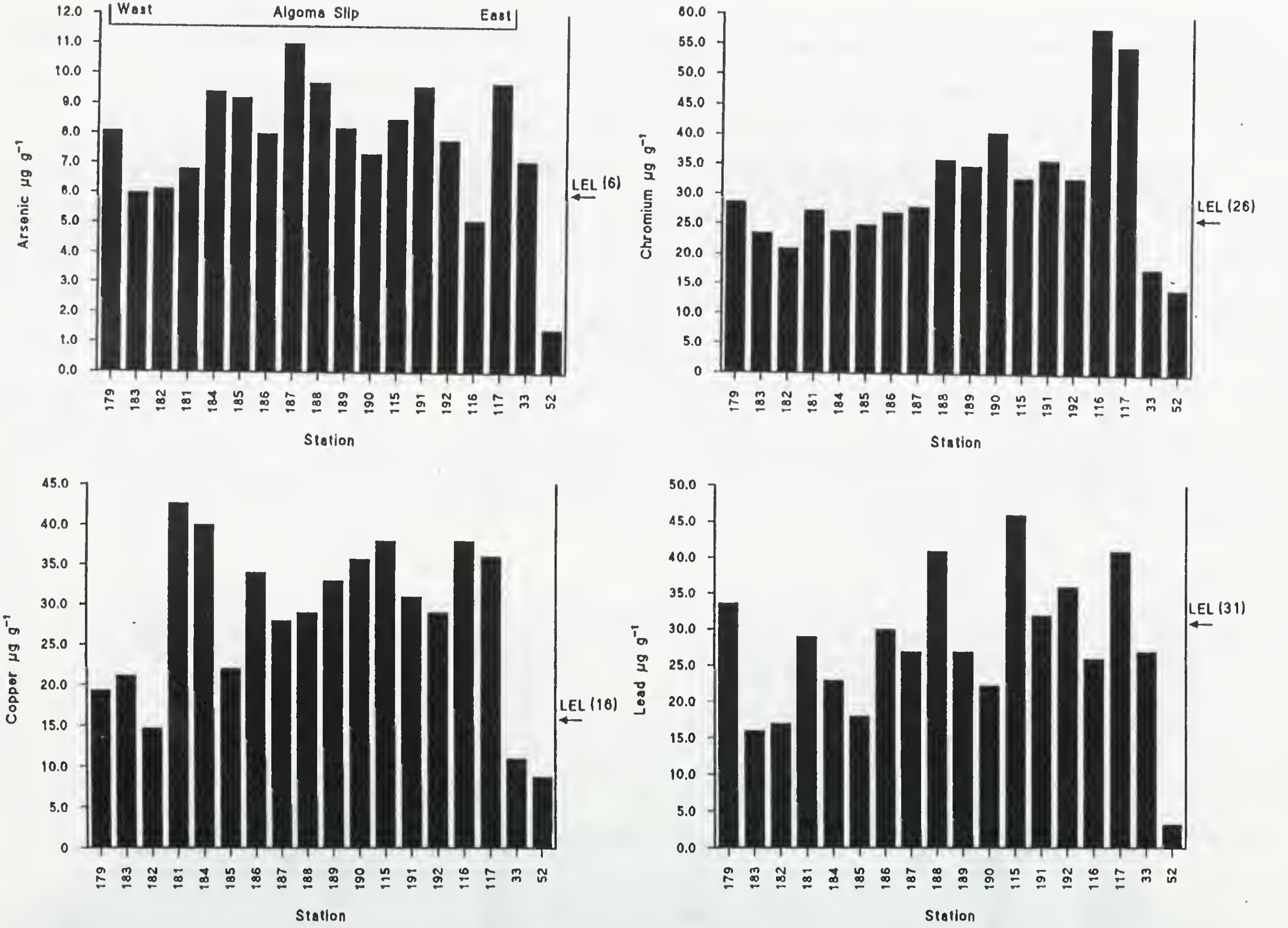

Figure 4: **Concentrations of arsenic, chromium, copper and lead in sediment samples from the Algoma Slip and Pointe aux Pins Bay.**

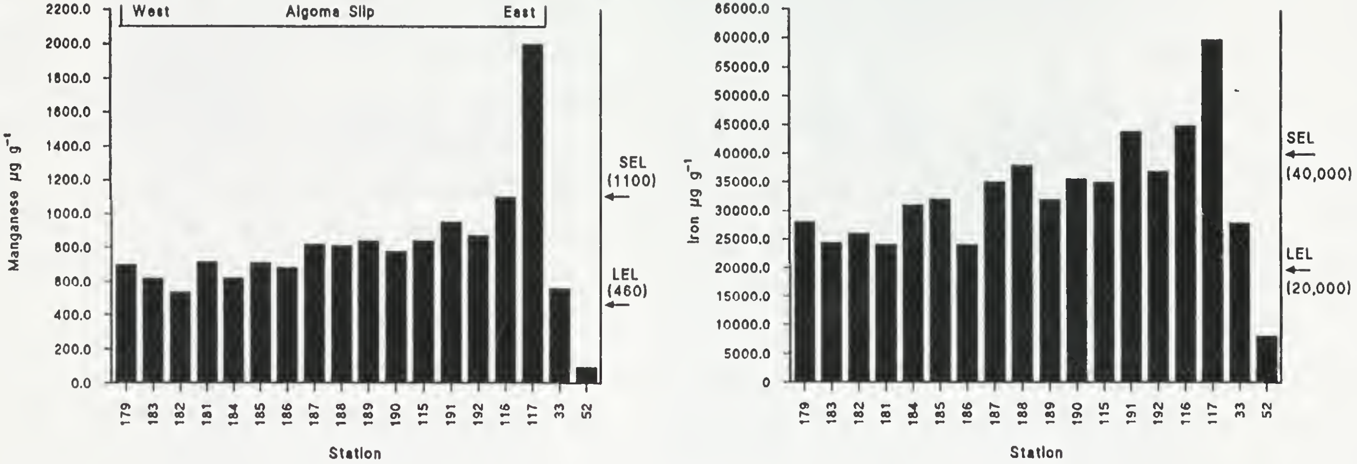

Figure 5: Concentrations of manganese and iron in sediment samples from the Algoma Slip and Pointe aux Pins Bay.

Table 6: **Concentrations of polycyclic aromatic hydrocarbons in sediment samples from the Algoma Slip and Pointe aux Pins Bay.** Where results for replicate samples are available, the mean and standard deviation are presented. Mean values in completely shaded cells exceed PSQG-LELs. Means exceeding PSQG-SELs are bolded and only partially shaded. All concentrations are in $\mu g.g^{-1}$ (dry weight).

	West <------ Algoma Slip ------> East																	Control
Station:	179	183	182	181	184	185	186	187	188	189	190	115	191	192	116	117	33	52
Number of replicates:	3	6[1]	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6[1]
Acenaphthene[2]	13.97 ± 8.99	13.18 ± 9.23	15.95	100.0	32.00	na	na	3.80	3.41	7.80	7.03	6.40	2.04	6.07	0.10	na	0.04 < W	0.04 < W ± 0.00
Acenaphthylene[2]	6.55 ± 1.31	2.76 ± 1.13	3.15	0.05 < W	2.20	na	na	2.22	1.47	0.99	1.24	3.30	0.86	2.51	0.07	na	0.05 < W	0.05 < W ± 0.00
Anthracene	**90.81** ± 19.80	27.59 ± 12.95	**55.00**	**90.00**	44.40	na	na	8.70	11.30	16.00	15.60	19.35	5.25	23.73	0.18	na	0.08	0.01 < W ± 0.00
Benzo(a)anthracene	83.94 ± 3.72	40.78 ± 20.79	40.50	90.00	24.00	na	na	16.97	16.31	29.00	18.60	32.00	8.97	29.60	0.76	na	0.25	0.02 < W ± 0.00
Benzo(b)fluoranthene[2]	56.58 ± 15.09	24.85 ± 15.60	58.00	0.06 < W	11.00	na	na	17.69	9.01	22.00	9.50	27.00	3.00	11.63	1.00	na	0.23	0.06 < W ± 0.00
Benzo(k)fluoranthene	24.33 ± 3.24	6.12 ± 1.68	18.45	30.00	9.10	na	na	7.08	4.50	7.80	8.19	8.76	5.93	6.05	0.38	na	0.18	0.02 < W ± 0.00
Benzo(g,h,i)perylene	21.88 ± 15.88	5.16 ± 1.26	**16.50**	0.04 < W	3.70	na	na	6.31	4.14	9.20	2.98	7.68	3.08	4.94	0.43	na	0.12	0.04 < W ± 0.00
Benzo(a)pyrene	42.27 ± 10.18	8.93 ± 2.17	19.94	50.00	11.00	na	na	13.50	6.89	15.00	8.59	15.89	4.78	8.82	0.77	na	0.20	0.04 < W ± 0.00
Chrysene	**90.75** ± 8.25	**40.17** ± 18.09	**41.50**	**80.00**	23.00	na	na	21.40	20.58	27.00	18.88	32.00	10.30	30.94	0.83	na	0.30	0.02 < W ± 0.00
Dibenzo(a,h)anthracene	6.19 ± 0.50	2.01 ± 0.74	**6.35**	0.04 < W	0.04 < W	na	na	1.67	1.43	3.40	0.95	2.10	1.30	1.79	0.13	na	0.06	0.04 < W ± 0.00
Fluoranthene	**362.5** ± 62.87	**185.9** ± 108.8	**168.0**	**490.0**	**130.0**	na	na	48.86	43.12	27.00	53.60	124.0	26.38	93.65	1.50	na	0.50	0.02 < W ± 0.00
Fluorene	**34.26** ± 11.19	**20.50** ± 12.37	**32.11**	**140.0**	**43.00**	na	na	4.92	5.69	12.00	11.22	10.45	3.38	11.64	0.11	na	0.05	0.04 < W ± 0.00
Indeno(1,2,3-cd)pyrene	26.31 ± 4.24	5.59 ± 1.29	12.77	0.04 < W	4.90	na	na	8.14	4.54	8.90	3.81	9.61	3.36	5.31	0.64	na	0.14	0.04 < W ± 0.00
Naphthalene[2]	15.04 ± 4.58	6.22 ± 0.86	18.22	340.0	43.00	na	na	12.27	7.18	12.00	17.72	6.76	5.59	14.64	0.31	na	0.13	0.06 < W ± 0.00
Phenanthrene	**236.7** ± 73.5	**163.0** ± 107.2	**172.0**	**720.0**	**230.0**	na	na	28.86	34.46	38.00	55.41	91.00	22.56	66.85	0.88	na	0.32	0.07 < W ± 0.00
Pyrene	**273.8** ± 46.95	**132.7** ± 76.40	**140.0**	**340.0**	**95.00**	na	na	38.98	31.08	46.00	39.98	90.00	20.06	69.00	1.20	na	0.42	0.06 < W ± 0.00
Total PAHs	**1385.9**[3] ± 162.2	685.6 ± 385.6	**818.4**[4]	**2470.0**[5]	**705.9**[6]	na	na	241.4	205.1	282.1	273.3	486.3	126.8	387.2	9.29	na	3.01	0.00 ± 0.00

NOTES: 1 - results are for 3 replicates, each split into a blind duplicate.
2 - PSQGs not yet available for this compound.
'< W' suffix = no measurable response (zero); less than reported value.
'na' = no data available.

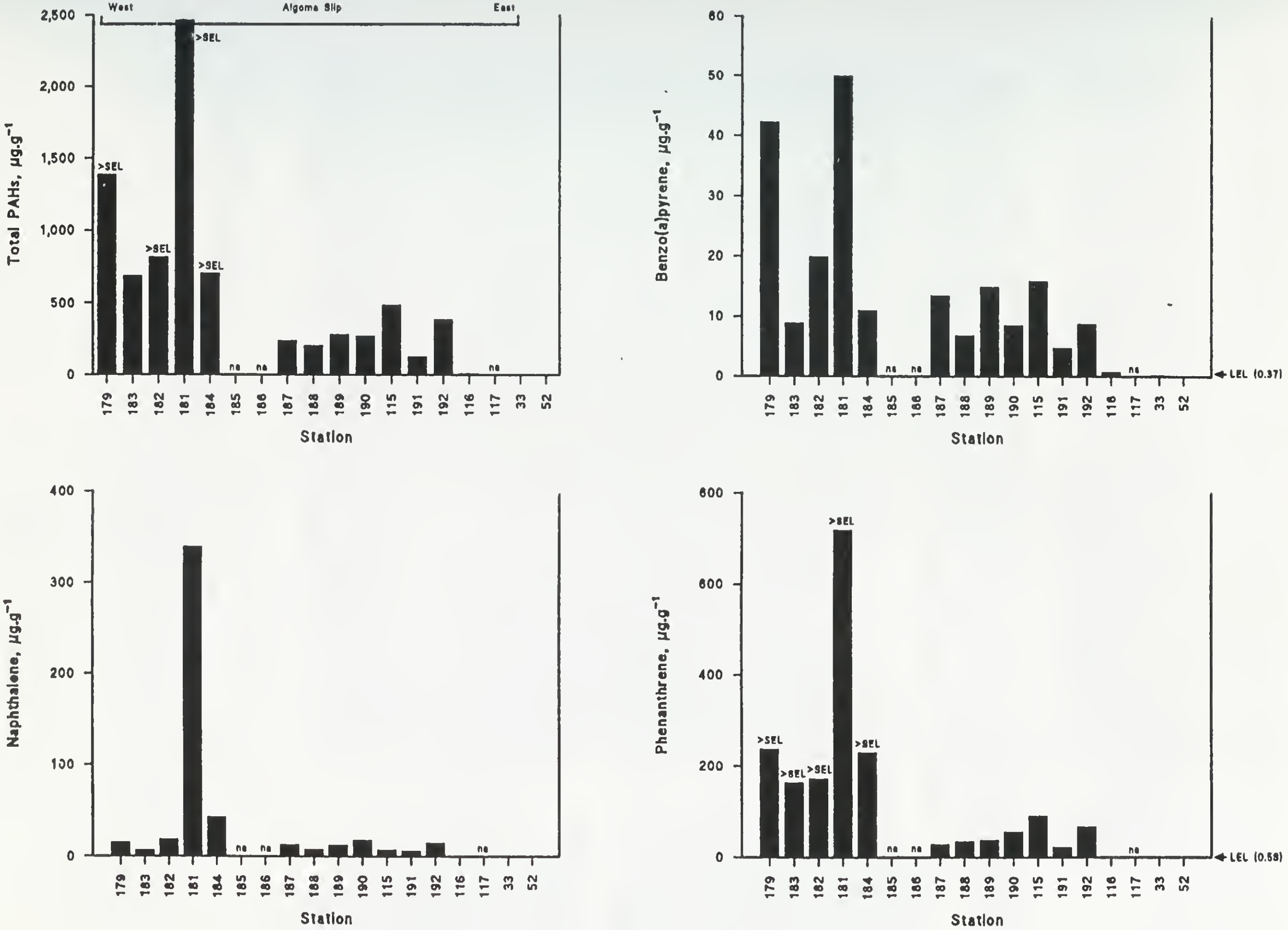

Figure 6: Concentrations of total polycyclic aromatic hydrocarbons (PAHs), benzo(a)pyrene, naphthalene and phenanthrene in sediment samples from the Algoma Slip and Pointe aux Pins Bay.

Table 7: **Concentrations of polycyclic aromatic hydrocarbons in surficial sediments collected from the Algoma Slip area and Point aux Pins Bay in 1985 and 1987** (Kauss and Hamdy, 1991; MOEE, unpubl. data). Values in completely shaded cells exceed PSQG-LELs; none exceed the respective PSQG-SELs. All concentrations are in $\mu g.g^{-1}$ (dry weight).

Station:	115		116	117		33	52
Year:	1985	1987	1987	1985	1987	1987	1987
Acenaphthene [1]	19.5	3.59	0.49	0.93	0.18	0.72	0.04<T
Acenaphthylene [1]	4.80	0.90	0.81	0.42	0.06	3.38	0.04<T
Anthracene	37.0	6.07	3.59	3.50	0.45	5.04	0.01<T
Benzo(a)anthracene	32.0	9.74	4.23	5.50	1.10	7.82	0.02<T
Benzo(b/k)fluoranthene [2]	32.5	11.5	5.42	4.32	1.52	11.8	0.08<T
Benzo(g,h,i)perylene	4.50	3.40	1.48	0.82	0.17	3.85	0.04<T
Benzo(a)pyrene	24.5	5.12	2.87	2.80	0.54	5.79	0.04<T
Chrysene	9.30	8.25	4.40	1.50	1.50	7.41	0.02<T
Dibenzo(a,h)anthracene	2.30	0.59	0.25	0.35	0.07	0.61	0.04<T
Fluoranthene	135	22.7	10.8	13.0	3.13	18.2	0.04<T
Fluorene	28.5	5.13	1.74	1.90	0.28	3.82	0.04<T
Indeno(1,2,3-cd)pyrene	5.30	3.56	1.73	0.82	0.20	4.08	0.04<T
Naphthalene [1]	29.0	9.56	1.10	3.30	0.57	3.47	0.04<T
Phenanthrene	185	22.4	8.73	14.0	1.75	19.8	0.07<T
Pyrene	71.5	18.0	8.50	7.40	2.59	14.9	0.06<T
Total PAHs	620.7	130.5	56.1	60.5	14.1	110.7	0.62<T

NOTES: 1 - PSQGs not yet available for this compound.

2 - Benzo(b)fluoranthene and Benzo(k)fluoranthene isomers could not be resolved in 1985 sediment samples and their concentrations have therefore been combined for the 1987 samples; however, PSQG guideline exceedences are for Benzo(k)fluoranthene.

'<T' suffix = a measurable trace amount; interpret with caution.

Table 8 presents a comparison of inorganic and organic contaminant concentrations in sediments from the Algoma Slip with these four other areas. All of the maximum inorganics and heavy metal concentrations in sediments from this group of locations exceeded the PSQG-LELs, and in numerous cases, also exceeded the PSQG-SELs. Where comparisons were possible, the maximum concentrations of total PAHs and of many individual PAH compounds in all areas also exceeded their respective PSQG-LELs. Overall, the group maximum concentrations of cyanide, a number of heavy metals and solvent extrractables were recorded for Buffalo River sediments, whereas the Algoma Slip contained the highest levels of most PAHs.

Principal components analysis was used to summarize the overall patterns in spatial variation in the inorganic and metal contaminants, PAHs, solvent extractables (oil and grease), and physical sediment quality among fifteen of the eighteen sites in the Algoma Slip and the St. Marys River. The first two axes explained over 66 percent of the total variance (Table 9).

The first axis (PC I) explained over 40 percent of the total variance (Table 9) and described a gradient in sediment quality from the west end of the slip (stations 179, 181, 182, 183, and 184) to the east end of the slip (station 116) and stations located outside the slip (stations 33 and 52) (Figure 7). This axis was positively correlated with all PAH compounds. Stations 179, 181, 182, 183, and 184 located in the extreme western end of the slip scored positively on PCI and had higher concentrations of PAHs than stations located in the eastern portion of the slip and outside the slip. Stations 179, 181, 182, and 184 were the only sites where total PAH concentrations exceeded PSQG-SELs. Positive correlations with PCI were also found with percent very fine to coarse sand and cyanide. PCI was negatively correlated with percent very coarse sand. Correlations of the remaining sediment quality parameters with PCI were generally quite low (Table 9).

The second axis (PCII) explained an additional 26 percent of the total variance and was positively correlated with all metals (Table 9). This axis separates stations located in the middle (stations 187, 188, 189, 190, 115, 191, and 192) and the eastern end (station 116) of the slip from the remaining sites (Figure 7). Stations 187, 188, 189, 190, 115, 191, 192, and 116 scored positively on PCI and generally had higher concentrations of most metals than stations located in the western end of the slip (stations 179, 181, 182, 183, and 184) and sites located outside the slip (stations 33 and 52). Metal levels at these sites are most likely attributable to loadings from the blast furnace sewer located approximately in the middle of the slip. PCII was also positively correlated with percent fines (silt and clay), solvent extractables (oil and grease), TOC, LOI, and percent very coarse sand (Table 9).

3.3 Sediment Bioassays

A summary of the sediment bioassay results is presented in Table 10. Mortality was extremely high (71% to 100%) for all three species exposed to sediments from stations 179, 181, 182, and 183. In 1987, static 10-day biossays showed that slip sediments were also acutely toxic to fathead minnows and burrowing mayfly nymphs, resulting in 100% mortality within 96 hours

Table 8: **Comparison of inorganics, heavy metals, solvent extractables and PAH concentrations in sediments fro areas in the Great Lakes receiving inputs from Steel and/or Coke manufacturing facilities.**
Shaded cells contain the maximum value of the five areas. All concentrations are in $\mu g.g^{-1}$ (dry weight).

Parameter	Algoma Slip [1]	Detroit River [2]	Buffalo River [3]	Welland River [4]	Hamilton Harbour [5]
Arsenic	5.1-11.0	1.9-29.0	7.9-27.4	8-11	10-63
Cyanide	0.01-1.6	0.01<W-4.45	na	nd	na
Cadmium	0.05-0.95	0.05<W-38.0	0.3-3.3	0.3-0.975	2.3-11.0
Chromium	21.0-58.0	14-260	23.5-85.8	91-670	98-250
Copper	14.7-42.7	11-530	53.6-123.4	43-168	94-170
Iron	24000-60000	200-160000	23700-35700	52000-118000	42000-93000
Lead	16.0-46.0	5.2-1100	79.7-225.5	38-87	180-450
Magnesium	3067-14000	na	na	na	na
Manganese	533-2000	170-2100	438.2-532.9	810-1210	1600-2800
Mercury	0.02-0.18	0.02<T-11.70	0.22-66.57	0.14-1.4	0.12-0.53
Nickel	13.5-38.0	12.0-130	33.9-43.4	98-390	49-66
Zinc	64.7-250	47.0-970	71.99-529.1	142-550	1200-3900
Solvent Extractables	588-10870	235-20057	na	780-3600	na
Acenaphthene	0.10-32.00	0.04<W-11.59	na	0.07	0.0-24.8
Acenaphthylene	0.07-6.55	0.05<W-5.35	na	nd	0.0-25.6
Anthracene	0.18-90.82	0.01<W-19.03	0.21-3.40	0.28	0.07-33.0
Benzo(a)anthracene	0.76-90.00	0.02<W-28.04	0.46-2.60	1.14	0.37-16.6
Benzo(b)fluoranthene	1.00-56.58	0.06<W-23.95	nd-5.50	0.61	0.72-31.1
Benzo(k)fluoranthene	0.38-30.00	0.02<W-8.85	0.32-1.15	1.91	0.27-27.8
Benzo(g,h,i)perylene	0.43-21.88	0.04<W-12.85	0.21-2.61	1.58	0.33-60.6
Benzo(a)pyrene	0.77-50.00	0.04<W-27.25	0.21-2.54	2.90	0.48-40.9
Chrysene	0.83-90.75	0.02<T-26.85	0.24-1.77	1.09	0.44-17.6
Dibenzo(a,h)anthracene	0.13-6.19	0.04<W-3.60	0.12-6.31	0.80	0.0-24.3
Fluoranthene	1.50-490.00	0.02<W-45.35	2.45-10.07	1.23	0.8-96.3
Fluorene	0.11-140.00	0.04<W-8.74	nd-0.64	0.09	0.0-107.0
Indeno(1,2,3-cd)pyrene	0.62-26.31	0.04<W-14.16	0.62-2.80	1.1	0.36-68.5
Naphthalene	0.31-340.00	0.04<W-2.40	na	0.06	0.0-193.0
Phenanthrene	0.88-720.00	0.07<W-50.58	0.67-9.60	0.66	0.31-118.0
Pyrene	1.20-340.00	0.06<W-63.77	1.40-21.95	1.22	0.69-72.7
Total PAHs	18.54-2389.0	0.02<T-351.85	(8.74-60.18)	14.77	5.07-742.8

NOTES: 1 - Data from this study, excluding results for stations 33 and 52.
2 - 1991 MOEE data for Michigan stations from L. St. Clair to L. Erie (Farara and Burt, 1993).
3 - Inputs from now-closed Donner-Hanna Coke Joint Venture and Republic Steel Corp (Niagara River Toxics Committe 1984).
4 - Sediments collected from two stations offshore and slightly downstream of the Atlas Steel outfall (Pope *et al.*, 1992)
5 - Long-term sensing data (Pope, 1993); Inputs from Stelco Inc. and Dofasco Inc.; upper limit for PAHs from Randle Re (Murphy *et al.*, 1991).
'na' = no data available.
'nd' = not detected.
'<W' suffix = no measurable response (zero); less than reported value.

Table 9: **Loadings on Sample Axes I and II by the 34 sediment chemical and physical variables used in the Principal Components Analysis.**

Parameter	PC I	PC II
Chrysene	0.967	-0.067
Pyrene	0.956	-0.146
Benzo(a)anthracene	0.953	-0.074
Phenanthrene	0.935	-0.158
Fluoranthene	0.933	-0.163
Benzo(a)pyrene	0.930	0.060
Benzo(k)fluoranthene	0.891	0.016
Fluorene	0.887	-0.158
Acenaphthene	0.884	-0.138
Anthracene	0.808	0.014
Acenaphthylene	0.758	0.050
Benzo(b)fluoranthene	0.756	0.097
Indeno(1,2,3-cd)pyrene	0.739	0.170
Solvent Extractables	0.717	0.479
Benzo(g,h,i)perylene	0.709	0.199
Naphthalene	0.695	0.176
Percent very coarse sand	-0.654	0.524
Percent very fine to coarse sand	0.617	-0.536
Dibenzo(a,h)anthracene	0.608	0.242
Cyanide	0.560	0.181
Manganese	-0.088	0.926
Magnesium	-0.054	0.905
Chromium	-0.079	0.894
Nickel	-0.062	0.878
Iron	-0.263	0.845
Zinc	-0.193	0.779
Loss on Ignition	0.285	0.761
Total Organic Carbon	0.378	0.746
Lead	0.245	0.657
Arsenic	0.215	0.615
Cadmium	-0.035	0.606
Mercury	0.239	0.558
Copper	0.201	0.557
Percent Silt and Clay	-0.104	0.510
Percent of Total Variance Explained	40.1	26.1

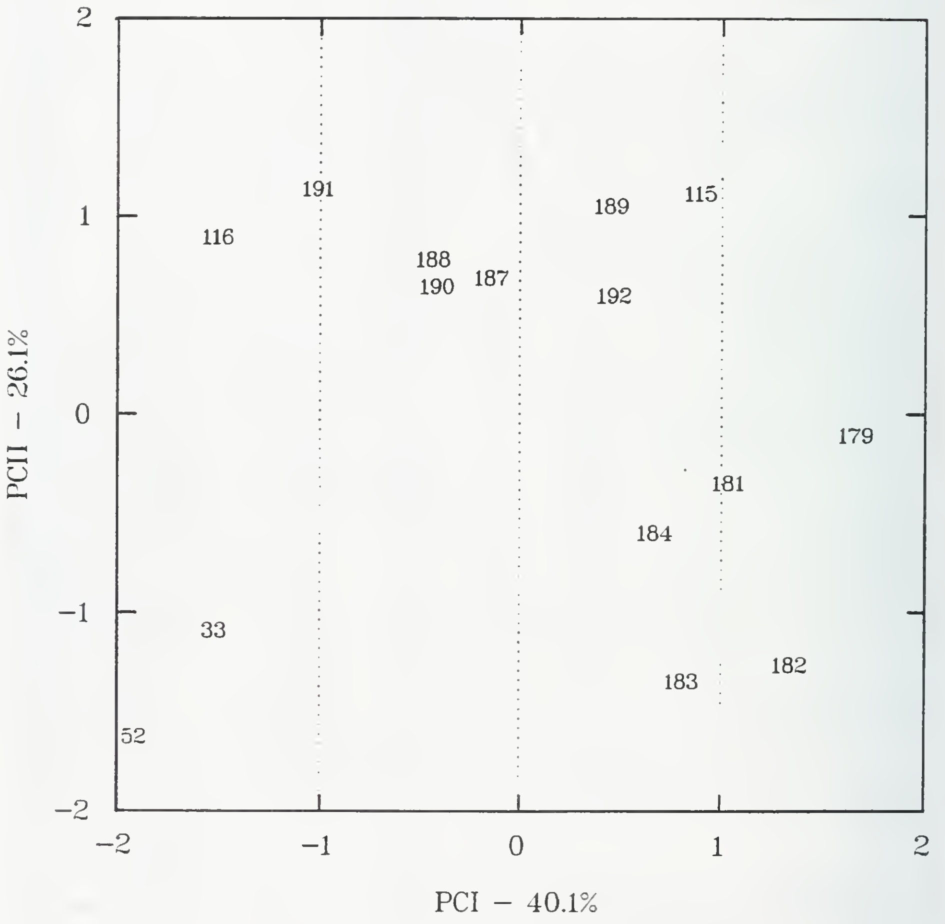

Figure 7: Scatterplot of Station Scores on the first two axes extracted by PCA on the 34 sediment chemical and physical variables.

(Hayton, 1987). In 1990, sediments from station 190 were not as toxic as those from other sites within the slip, as indicated by mayfly and fathead minnow mortality rates of 23.3 and 4.1 percent, respectively. Statistical analysis showed that mortality was significantly correlated with sediment concentrations of solvent extractables and PAHs (Bedard and Petro, 1992; Bedard, pers. comm.).

Sediments from station 52, located in Point Aux Pins Bay, produced fathead minnow mortality rates higher than those of the background site. Although this may indicate moderate toxicity for sediments from this site, the results are generally inconclusive, since mortality and growth of chironomids and mayflies were not significantly higher than with Honey Harbour background control sediment.

Table 10: Results of sediment bioassays using chironomid larvae, burrowing mayfly nymphs and juvenile fathead minnows [1].

Station	Location	Chironomids		Mayflies		Minnows
		Mortality, %	Wet Weight, g	Mortality, %	Wet Weight, g.	Mortality, %
Background	Honey Harbour	11.0 ± 7.7	18.6 ± 1.2	6.6 ± 5.7	4.4 ± 1.2	0.0 ± 0.0
52	Point aux Pins Bay	13.3 ± 6.7	17.4 ± 0.9	10.0 ± 10.0	3.6 ± 1.0	20.8 ± 36.0
179	West End of Algoma Slip	100 ± 0.0	na	100 ± 0.0	na	na
181		100 ± 0.0	na	100 ± 0.0	na	100 ± 0.0
182		100 ± 0.0	na	100 ± 0.0	na	87.5 ± 21.6
183A [2]		77.7 ± 19.2	na	100 ± 0.0	na	91.6 ± 14.4
183B [2]		100 ± 0.0	na	100 ± 0.0	na	70.8 ± 50.5
190	Middle of Slip	0.0 ± 0.0	12.5 ± 0.9	23.3 ± 15.2	4.0 ± 1.7	4.1 ± 7.2

NOTES:

1 - Mean and standard deviaton of 3 replicates.

2 - 183A and 183B data represent results of three replicates each split into an A and B portion after homogenization.

'na' = no data available.

Sediment bioassays have also been completed by Jaagumagi *et al.* (1991) on sediments collected from several stations in the St. Marys River in 1987, but not from the Algoma Slip. Mayfly mortality was as high as 20 percent at sites located downstream of Sault Ste. Marie. Zero mortality was noted for fathead minnows at all locations evaluated during the 1987 study. Mortality rates reported for sediments from Hamilton Harbour, which also receives contaminant inputs from the steel industry, ranged from 0-22 percent for mayflies, and from 0-100 percent for fathead minnows (Krantzberg, 1991).

3.4 Benthic Invertebrates

In total, 25 benthic invertebrate taxa (excluding immature tubificids) were identified from the samples collected at the 18 sampling stations in the study area (Table 11). All species counts per sample, tabulated by station and replicate, are presented in Appendix IV. Species

Table 11: Benthic invertebrate species list.

- AMPHIPODA:
  - Gammaridae:
    - *Gammarus*

- DIPTERA:
  - Ceratopogonidae:
    - *Bezzia*
  - Chironomidae:
    - Chironominae:
      - *Chironomus* (Chironomus)
      - *Cladotanytarsus*
      - *Cryptochironomus*
      - *Glyptotendipes*
      - *Harnischia*
      - *Phaenopsectra*
      - *Polypedilum*
      - *Rheotanytarsus*
    - Orthocladiinae:
      - *Epoicoclodius*
      - *Heterotrissocladius*
      - *Nanocladius*
    - Tanypodinae:
      - *Apsectrotanypus*
      - *Procladius*

- EPHEMEROPTERA:
  - Ephemeridae:
    - *Ephemera*
    - *Hexagenia*

- GASTROPODA:
  - Physidae:
    - *Physa gyrina*
  - Valvatidae:
    - *Valvata*

- ISOPODA:
  - Asellidae:
    - *Caecidotea*[1]

- OLIGOCHAETA:
  - Tubificidae:
    - Imm. tubificid w/ bifid chetae
    - Imm. tubificid w/ simple chetae
    - *Spirosperma ferox*
    - *Quistadrilus multisetosus*
  - Naididae:
    - *Nais barbata*
    - *Nais*
    - *Nais/Dero*

- PELECYPODA:
  - Sphaeriidae:
    - *Pisidium*

[1] - *Caecidotea* and *Asellus* are generally united under the genus *Asellus* (see Pennak, 1978).

abundances, or density (as number.m^{-2}) at each station are presented in Appendix V. These values were calculated using multiplication factors which normalized the individual species counts, based on the total volume of each core replicate and the surface area of the core tube.

The low numbers of individuals and taxa may be attributable to the sampling technique, in which 1.5 litres of sediment was subsampled from the larger homogenized sediment core. Core samples ranged in length from 100 mm to 432 mm, with most in excess of 200 mm (Appendix II). The homogenization of the entire core likely diluted the numbers of individuals and taxa in the samples, due to the fact that most invertebrates are near the surface of the sediments. Naidids, for example, are usually concentrated at the sediment-water interface, and are rarely more than 2-4 cm below the surface (Milbrink, 1973). Similarly, tubificids are most abundant 2-4 cm below the surface, but can be found at depths of up to 15 cm (Wetzel, 1983). Robbins *et al.* (1989) noted tubificids between 0 and 15 cm in sediment cores collected from Lake Erie. Sediment cores collected from the St. Marys River in 1987 found most individuals at depths less than 10 cm, and noted chironomids at depths ranging from 0-6 cm (Pope, 1990).

All taxa, with the exception of the chironomid *Apsectrotanypus*, have been identified by previous studies in the St. Marys River (Burt *et al.*, 1988; Jaagumagi *et al.*, 1991). The number of taxa found at each station was quite variable, ranging from zero at several sites within the slip to a high of 12 at station 33 (Figure 8). Relatively high numbers of taxa were also found at stations 117 (eight) and 52 (seven). No benthic invertebrates were found at six stations within the slip (182, 186, 187, 189, 190 and 192), and only one taxon was found in samples from another six stations (181, 184, 185, 188, 115 and 116). Stations 179 and 183 had relatively high numbers of taxa. This is surprising, given that these sites were located at the extreme western end of the slip. This situation may be the result of invertebrate drift from East Davignon Creek or Bennett Creek, both tributaries to this end of the slip (see Figure 1). The sediments from stations 179 and 183 had relatively low concentrations of most metals when compared to the other sites, however they also had very high concentrations of PAHs. The sediments from station 183 were also quite toxic to chironomids, mayflies, and fathead minnows in laboratory bioassays.

The mean number of benthic invertebrates per sample for each station is illustrated in Figure 8. The greatest numbers of individuals were found at stations 33 and 52, both outside the Algoma Slip. The low numbers of individuals and taxa at most stations within the Algoma Slip are most likely due to the toxic nature of the sediments, as indicated by the elevated levels of metals, inorganics, and PAHs. Figure 8 also presents the Shannon-Weaver diversity index for all replicates combined for each station. Diversities could not be calculated for stations 182, 186, 187, 189, 190, and 192 because no invertebrates were found at these sites. Stations at which only one invertebrate taxon was present had diversities of zero. Diversity indices within the slip ranged from zero at six stations in the slip (181, 184, 185, 188, 115 and 116), to 1.72 at station 117 at the eastern end of the slip. The diversity indices of 1.05 and 1.48 at stations 179 and 183, respectively, reflect the higher-than-normal numbers of individuals and tax at these stations. The highest diversity was found at station 33, with a value of 2.03. In comparison, the diversity index at upstream control station 52 was 1.51.

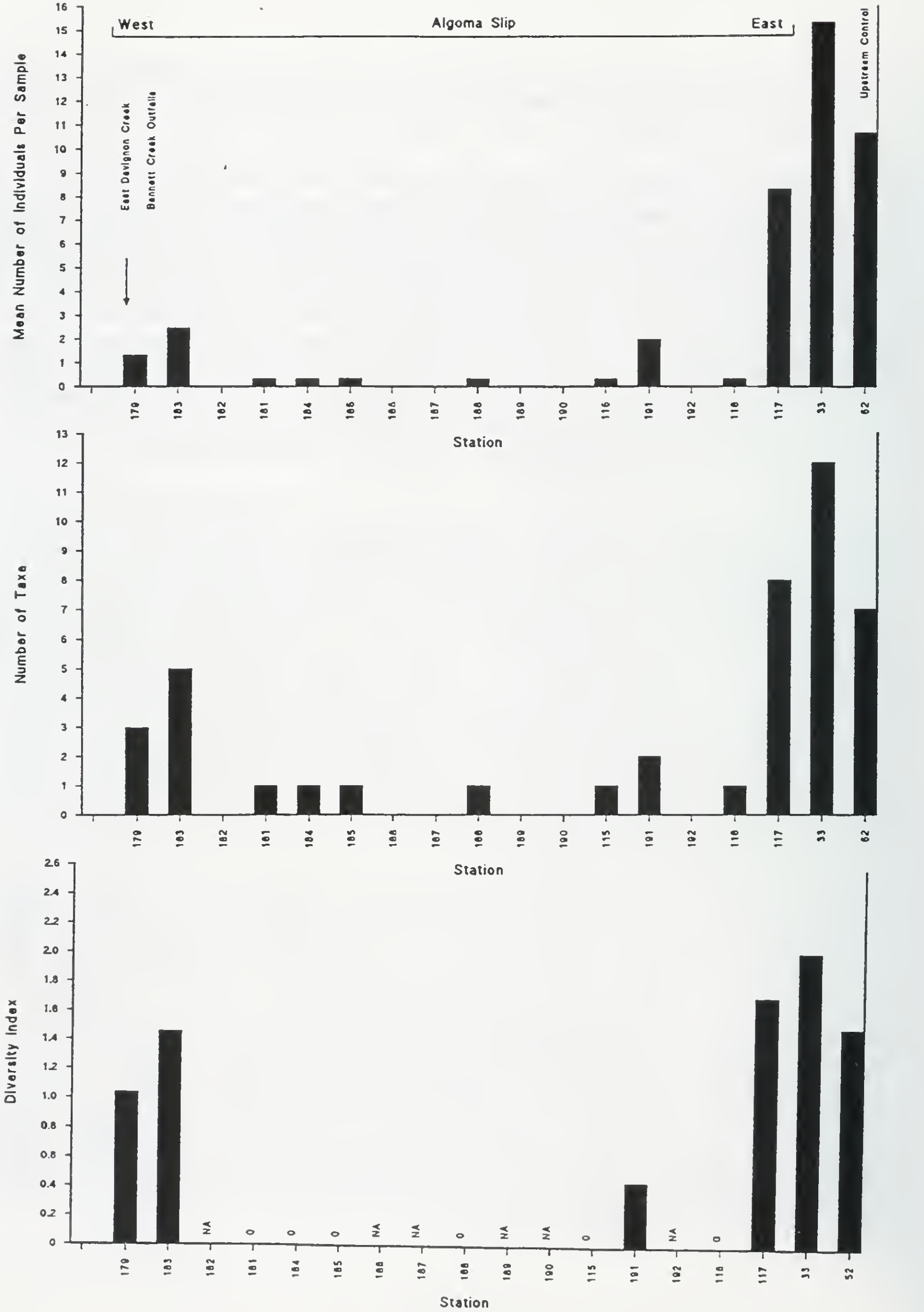

Figure 8: The mean number of invertebrates per sample, the total number of taxa and the Shannon-Weiner Diversity Index for each station.

Several invertebrate taxa may be used as indicator species for the purpose of evaluating environmental quality. For example, nymphs of mayflies, such as *Hexagenia*, *Ephemera*, and *Caenis*,are generally considered intolerant of polluted conditions (Schloesser, 1988; Fremling, 1964; Winner *et al.*, 1980; Roback, 1974). *Hexagenia* was only found in samples from stations 33and 52, both located outside the slip, indicating unimpaired conditions at these sites. The absence of mayflies from all stations in and near the Algoma Slip is not surprising, given the toxic nature of the substrate. Schloesser (1988) and Hiltunen and Schlosser (1983) noted that *Hexagenia* was generally absent in contaminated sediments of the St. Marys River that contained visible oil, downstream of Sault Ste Marie.

Tubificids are generally characteristic of areas of organic enrichment (Lauritsen *et al.*, 1985; Cook and Johnson, 1974), and certain species such as *Tubifex tubifex* are also considered tolerant of elevated levels of metals such as copper, chromium and zinc (Winner *et al.*, 1980; Popovic and Popovic, 1977). Tubificids were either totally absent or occurred in very low numbers in sediments within the slip (the maximum was $584.m^{-2}$ at station 183, Appendix V), again reflecting the extreme toxicity of the sediments.

Some chironomids, such as *Chironomus* and *Procladius*, are also considered pollution tolerant, (Johnson *et al.*, 1987; Cook and Johnson, 1974; Nalepa and Thomas, 1976). *Procladius* was found at stations 183, 115 and 188 within the slip, and at station 117 at the eastern end of the slip. *Chironomus* was the dominant chironomid at station 179.

Mean numbers of oligochaetes and chironomids per sample are illustrated in Figure 9. Station 33 had relatively high numbers of oligochaetes, and station 117 had relatively high numbers of chironomids.

Previous surveys of the benthos community of the St. Marys River, including areas in or near the Algoma Slip, were conducted by the MOE in 1985 and 1987 (Burt *et al.*, 1988; Jaagumagi *et al.*, 1991). Jaagumagi *et al.* (1991) noted that the benthic invertebrate populations were severely reduced at and downstream of, the Algoma Steel discharges. One site evaluated just outside the Algoma Slip had a small population of *Hexagenia limbata* and a few species of oligochaetes. Burt *et al.* (1988) also identified impacted benthic invertebrate communities downstream of the Algoma Steel, St. Marys Paper, and the easterly Sault Ste. Marie Water Pollution Control Plant.

Impacted benthic invertebrate communities have also been documented in the vicinities of other steel and/or coke manufacturing facilities in Hamilton Harbour (Pope, 1993; Krantzberg, 1991) and the Welland River (Pope, 1992). The benthos community of Hamilton Harbour, for example, was found to be dominated by pollution-tolerant species such as *Limnodrilus hoffmeisteri*, *Tubifex tubifex* and *Quistadrilus multisetosus* (Pope, 1993). Chironomids were generally absent, with the exception of pollution-tolerant species of *Chironomus* and *Procladius*. A similar study by Krantzberg (1991) also found large numbers of similar taxa, including the tubificids *Limnodrilus hoffmeisteri, Quistadrilus multisetosus, Tubifex tubifex*, and *Limnodrilus*

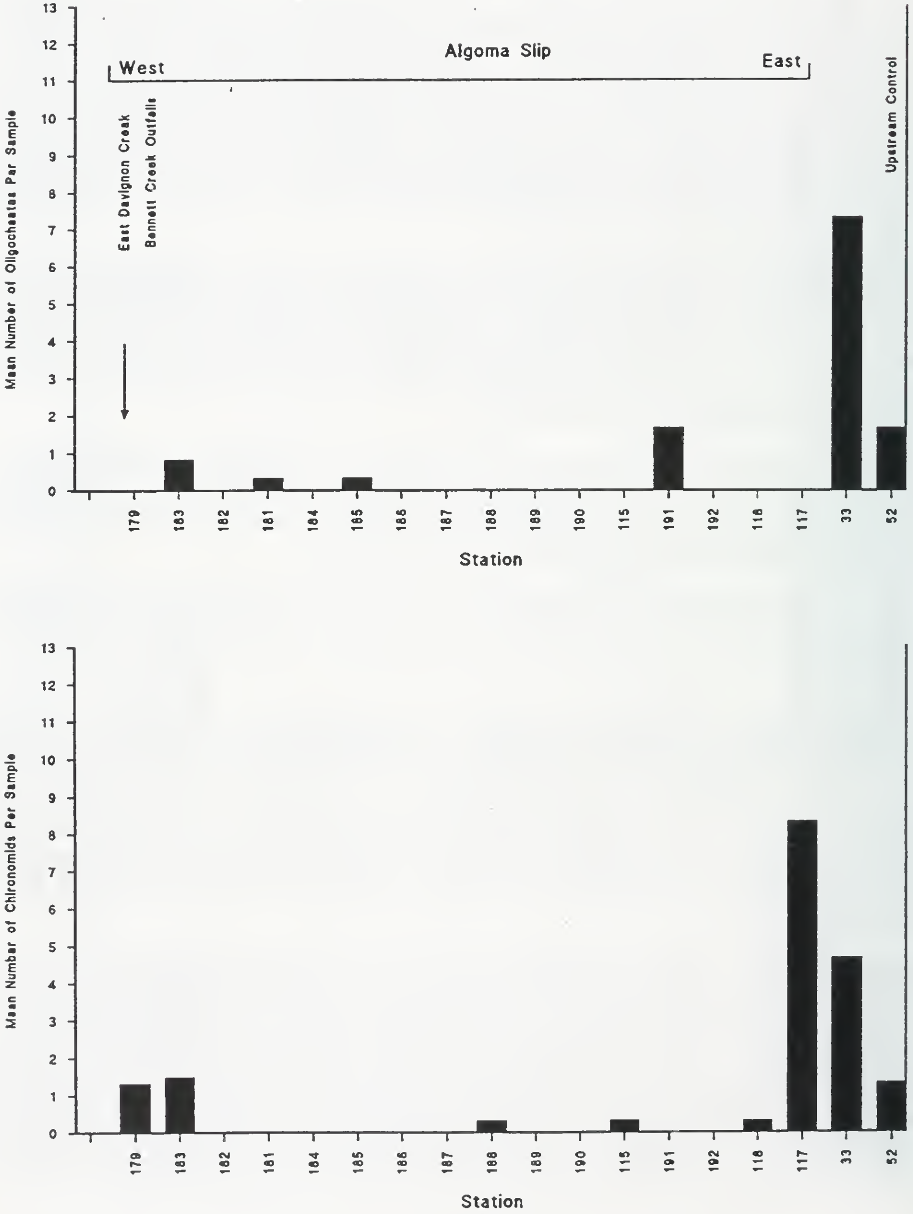

Figure 9: The mean number of oligochaetes and chironomids per sample.

cervix. Unlike the samples from the Algoma Slip, large numbers of oligochaetes were found in sediments from Hamilton Harbour, although this difference may be due to different sampling methods (coring *vs* Ponar). Total oligochaete abundances (almost exclusively tubificids) at sites in the harbour ranged from $5,852.m^{-2}$ to $21,108.m^{-2}$. The benthic community downstream of the Atlas Steel outfall in the Welland River was dominated by the tubificids *Limnodrilus hoffmeisteri*, immature tubificids, and the chironomids *Procladius* and *Chironomus*. A reduction in the total number of oligochaetes was observed immediately below the discharge.

3.5 Water Physical and Chemical Characteristics

At most stations there was little difference in water temperature, dissolved oxygen or pH levels at the surface, mid-depth or just above the sediment surface and with one exception, levels were within applicable Provincial Water Quality Objectives (PWQOs) for the protection of aquatic life (Table 12). However, at station 179 at the west end of the slip, dissolved oxygen was zero near the bottom. This is far below the PWQOs of 4 mg.l^{-1} for the protection of warm-water fish and 5 mg.l^{-1} for the protection of cold-water fish (MOE, 1984).

Current speed was usually greatest just below the surface, and was highest at station 33, adjacent to the Algoma Steel dock outside the slip and just above the Great Lakes Power Corporation headrace (Figure 1). The bottom current speed at this location was 0.28 m.s^{-1}, which is close to the minimum of $\sim 0.30 \text{ m.s}^{-1}$ required for erosion of consolidated coarse silt (62-31 μm diameter particles). Speeds at the other locations within the slip ($0.00\text{-}0.10 \text{ m.s}^{-1}$) were below this minimum and also below the required minimum for the erosion of unconsolidated coarse silt erosion ($\sim 0.15 \text{ m.s}^{-1}$).

3.6 Sediment Volume and Associated Contaminants

The approximate volume of sediments in the Algoma Slip was calculated using data on sediment depth (Appendix I) for Transects A to L inclusive (Figure 1). The total volume of sediment is about $14,340 \text{ m}^3$. The greatest accumulations of sediment are located in the upper (western) half of the slip, near the mouths of Bennett and East Davignon Creeks. At some locations the depth of material in this area exceeded 1.75 metres. Sediments from this area were also the most obviously contaminated with oil and coal tar, contained the highest concentrations of polycyclic aromatic hydrocarbons, and were very toxic in laboratory bioassays.

The upper end of the slip, represented by Transects A, B and C, contains about $4,150 \text{ m}^3$ of sediment, or 29 % of the total sediment volume in the slip. This area also has the greatest density of sediment sampling stations (stations 179, 181, 182, 183 and 184). Using averages for the sediments from these five stations for solvent extractables ($5,378 \ \mu\text{g.g}^{-1}$), total PAHs ($1,213 \ \mu\text{g.g}^{-1}$, dry), moisture content (29.5 %) and field density (1.535 g.cm^{-3}), the calculated weight of oils and greases and of total PAHs associated with these sediments alone totals 10,117 kg and 2,282 kg, respectively.

Table 12: **Physical and chemical characteristics of water at sediment sampling stations.** Values in completely shaded cells do not meet Provincial Water Quality Objectives (MOE, 1984).

Station	Water Depth, m.	Sample Depth, m.	Temperature, °C	Dissolved Oxygen, $mg.l^{-1}$	pH	Conductivity @25 °C, $\mu s.cm^{-1}$	Current Speed, $m.s^{-1}$
179	4.00	0.50	19.0	7.65	7.54	169	0.08
		2.00	18.3	7.85	7.59	139	0.10
		3.85	18.3	0.00	7.50	182	0.00
183	2.50	0.50	18.8	7.93	7.93	na	0.09
		1.25	na	na	na	na	na
		2.35	18.3	7.30	7.94	na	0.00
182	6.00	0.50	19.1	8.10	7.91	na	0.04
		3.00	18.5	7.50	na	na	0.01
		5.85	17.4	7.50	8.00	na	0.01
181	7.00	0.50	18.9	8.05	7.90	na	0.01
		3.50	18.3	8.80	7.83	na	0.01
		6.85	18.2	7.45	7.87	na	0.00
184	6.50	0.50	18.8	7.75	7.91	na	0.08
		3.25	18.5	7.40	7.90	na	0.04
		6.35	18.4	7.60	7.89	na	0.03
185	7.00	na	na	na	na	na	na
186	7.00	na	na	na	na	na	na
187	8.00	0.50	18.7	8.30	7.85	na	0.03
		4.00	18.2	8.50	7.79	na	0.01
		7.85	18.3	8.30	7.86	na	0.01
188	6.50	0.50	18.8	8.60	7.86	na	0.00
		3.25	18.3	8.35	7.80	na	0.01
		6.35	18.2	7.30	7.93	na	0.00
189	6.50	na	na	na	na	na	na
190	9.00	0.50	18.8	8.80	7.77	na	0.00
		4.50	18.3	8.45	7.81	na	0.00
		8.85	18.3	7.50	7.92	na	0.00
115	8.00	0.50	18.8	8.80	7.77	na	0.02
		4.00	18.4	8.75	7.90	na	0.00
		7.85	18.2	7.45	7.91	na	0.00
191	8.00	na	na	na	na	na	na
192	8.50	na	na	na	na	na	na
116	11.50	0.50	18.5	8.90	7.68	na	0.06
		5.75	18.2	8.90	7.65	na	0.06
		11.35	17.9	7.85	7.67	na	0.00
117	9.50	0.50	18.5	8.95	7.63	na	0.04
		4.75	18.3	9.00	7.64	na	0.01
		9.35	18.3	9.10	7.63	na	0.00
33	9.50	0.50	18.3	9.25	7.66	na	0.34
		4.75	18.3	9.25	7.66	na	0.38
		9.35	18.2	8.60	7.66	na	0.28
52	4.50	0.50	17.1	9.15	7.23	97	0.00
		2.25	17.3	9.20	7.64	97	0.06
		4.35	16.9	8.70	7.66	97	0.09

NOTES: 'na' = no data available.

4.0 Summary and Conclusions

1. The Algoma Slip contains sediments of varying physical characteristics, ranging from hard-packed sandy material containing coal particles and coal tar, to gravel or clay. Silty sand was also present, and the percentages of fines (silt and clay) were generally higher at the eastern end of the slip, near the mouth.

2. The greatest accumulations of sediment, in terms of depth, are located in the upper (western) half of the slip, near the discharges of Bennett and East Davignon Creeks. Sediments from this area were also the most obviously contaminated with oil and coal tar, contained the highest concentrations of polycyclic aromatic hydrocarbons, and were very toxic to laboratory bioassay organisms. At some locations the depth of material in this area exceeded 1.75 metres.

3. Overall, sediments within the Algoma Slip are 'marginally to significantly polluted', as indicated by the elevated concentrations of inorganics and metals, and PAHs. With the exception of mercury, levels of most metals exceeded the respective PSQG-LELs. The concentrations of total PAHs as well as of 12 of the 16 PAH compounds also exceeded the respective PSQG-LELs at the majority of the 16 stations sampled in the slip. However, concentrations of iron, manganese, total PAHs and of up to eight individual PAH compounds were above their respective PSQG-SELs at some stations, thereby placing these sediments in the category of 'grossly polluted'. Also, solvent extractables (oils and greases) concentrations exceeded the open water disposal guideline at most stations within the slip.

4. The low numbers of benthic invertebrate taxa and individuals found at most stations in the slip indicates that the benthic-invertebrate community within the slip is severely impaired. Even pollution-tolerant taxa were absent or in low numbers at most stations from this area. This impact is most likely due to the high PAH concentrations in slip sediments. The benthic invertebrate communities at two stations located outside of the slip were relatively unimpaired. Nymphs of the pollution-intolerant burrowing mayfly *Hexagenia* were only found at these two stations.

5. Laboratory sediment bioassays confirmed that sediments from stations in the west end of the slip are highly toxic to chironomid larvae, mayfly nymphs, and fathead minnows. The sediment from a station in the middle of the slip was moderately toxic, and sediment from the upstream control station in Point aux Pins Bay elicited mortality rates only slightly higher than the reference background sediment.

6. Currents are normally fairly slow in the slip, suggesting that there may be little potential for resuspension of contaminated sediments. It is, however, important to note that this survey occurred during a general strike at Algoma Steel, and there was no commercial vessel traffic in the slip. Much higher current speeds are likely to occur as a result of propeller-induced turbulence during vessel movement. If this should also coincide with

a period of high flow from the two tributaries, resuspension and movement of fine (contaminated) sediment out of the slip could occur, with resultant downstream contamination. Calculations based on field data have shown that there is a significant volume of sediments in the slip (i.e., at least 14,340 m^3) and that uppermost portion of the slip, which contains about 29 % of this total, also has a large amount of sediment-associated contamiants such as oils and greases and total PAHs (i.e., 10.1 tonnes and 2.3 tonnes, respectively).

5.0 Recommendations

1. Due to contaminant concentrations and the toxic nature of the sediments within much of the Algoma Slip, various remediation options should be considered, including dredging and confined disposal of contaminated sediments or treatment. However, such measures would be most cost-effective after contaminant inputs to the slip have been reduced to the maximum extent possible. Furthermore, any dredging, whether maintenance or remedial, should only be conducted under conditions that minimize or prevent the escape of resuspended material to the St. Marys River.

2. After the above remedial measures have been completed, sediment quality and benthic invertebrate community samples should be collected to determine the effectiveness of contaminant removal.

3. If additional benthic invertebrate community surveys are conducted in this area, samples of a larger surface area should be taken to better evaluate the numbers of organisms and taxa.

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Appendix I

Diver's Observations of Sediment Characteristics

Adapted from Integrated Explorations(1990) report.

Transect	Distance from North shore, m.	Water Depth, m.	Sediment Depth, m.	Sediment Volume, m^3	Sediment Description	Appearance of Plastic Probe	Sediment Sampling Station Number
A	0	4.9	0.75	9.6	hardpacked, coarse, dark, small particles.	brown spots.	--
	11	4.6	1.75	105	hardpacked small particles; with coal.	streaked brown.	--
	21	4.9	0.95	61.1	hardpacked small particles; with large coal pieces.	streaked brown.	--
	31	3.7	0.90	65.0	hardpacked small particles; with coal.	streaked brown-black (heavily).	179
	41	2.2	>1.75	> 142	hardpacked, small particles; with coal.	streaked brown-black.	--
	51	0.6	>1.75	> 156	fine small particles.	streaked brown-black.	--
	61	0.6	0.90	88.4	very fine, hardpacked sand.	streaked brown-black (heavily).	--
	71	0.6	>1.75	> 1211	very soft sand.	streaked brown (lightly).	--
B	0	6.5	1.05	19.7	hardpacked, coarse, dark, small particles.	streaked brown.	181
	11	7.4	0.45	27.0	hardpacked small particles over gravel.	streaked brown-black.	--
	21	5.5	1.35	86.8	hardpacked small particles.	relatively clean.	182
	31	3.7	1.25	90.3	hardpacked small particles.	relatively clean.	--
	41	1.8	1.20	97.6	hardpacked sand; with small particles.	streaked brown-black (heavily).	183
	51	0.6	0.30	110	small particles over clay.	streaked brown-black.	--
	61	0.6	0.55	142	small particles, over clay; with gravel.	streaked brown-black (heavily).	--
C	0	8.0	0.70	140	small gravel.	streaked brown-black.	--
	9	8.3	0.55	231	gravel and debris.	streaked brown-black.	--
	19	6.8	1.50	663	small particles, over gravel.	streaked brown-black (less so).	--
	29	5.8	0.80	353	small particles.	streaked brown.	184
	39	4.6	0.45	356	small particles, over clay.	clean.	--
D	0	8.0	0.75	214	light, small particles.	streaked brown-black.	--
	12	8.0	0.50	262	small particles, over small gravel.	streaked brown.	--
	22	6.8	0.10	47.5	gravel.	streaked brown.	--
	32	5.8	1.25	594	small particles.	streaked brown (lightly).	185
	42	3.1	0.01	4.75	clay face (wall).	clean.	--
	52	0.6	0.00	0.0	clay ledge.	clean.	--
E	0	7.4	0.35	93.5	small particles, over light gravel.	streaked brown (lightly).	--
	10	8.0	0.75	400	light gravel.	streaked brown (lightly).	--
	20	7.1	0.90	480	small particles, over small gravel.	streaked brown (lightly).	--
	30	6.2	1.25	666	soft, small particles.	streaked brown (lightly).	186
	40	4.9	1.30	693	small particles.	streaked black (heavy coal dust).	187
	50	1.8	0.00	0.0	clay ledge.	clean (brown clay).	--
F	0	8.6	0.00	0.0	rocks, gravel and concrete.	clean.	--
	11	8.3	0.45	306	gravel.	streaked brown (lightly).	--
	21	7.7	0.50	296	light gravel.	streaked brown (lightly).	--
	31	7.1	0.60	356	hardpacked small particles.	streaked brown-black (lightly).	188
	41	6.5	0.80	473	hardpacked small particles.	streaked brown (lightly).	189
	51	5.5	1.25	740	hardpacked small particles.	streaked brown (lightly).	--
	61	3.7	0.35	207	hardpacked small particles and rocks	streaked black (lightly).	--

Transect	Distance from North shore, m.	Water Depth, m.	Sediment Depth, m.	Sediment Volume, m^3	Sediment Description	Appearance of Plastic Probe	Sediment Sampling Station Number
	71	0.3	0.20	35.5	rocks.	clean.	--
G	0	7.7	0.05	12.9	very fine gray grit.	clean.	--
	10	8.6	0.25	129	very fine gray grit; with boulders.	clean.	--
	20	8.6	0.75	388	very fine gray grit; with macrophytes.	clean.	190
	30	8.6	0.10	51.7	very fine gray grit; with macrophytes.	clean.	--
	40	7.4	0.25	129	very fine gray grit over fine gravel.	clean.	--
	50	8.0	0.03	15.5	very fine gray grit over fine gravel.	clean.	--
	60	5.5	0.05	25.8	very fine gray grit over large gravel.	clean.	--
	70	1.2	0.13	44.0	gray grit with gravel and cobble.	clean.	--
H	0	8.0	0.00	0.0	large boulders.	clean.	--
	12	8.3	0.02	9.9	fine sand over cobble; with rocks.	streaked black (lightly).	--
	20	8.6	0.12	43.2	fine gray sand; with detritus.	clean.	--
	30	8.6	0.75	338	fine gray sand; with detritus.	clean.	--
	40	8.3	0.65	293	detritus and fine small particles, over fine gravel.	clean.	--
	50	7.7	1.25	563	very soft, fine gray grit.	clean.	191
	60	8.0	0.75	338	fine gravel.	clean.	--
	70	7.1	0.25	124	very fine muck; gas bubbles.	clean.	--
I	0	6.8	0.00	0.0	concrete.	clean.	--
	10	8.9	0.01	4.6	boulders.	clean.	--
	20	8.9	0.10	45.8	detritus and fine gray gravel over sand; with clay.	clean.	--
	30	8.3	0.30	137	fine gray sand.	clean.	--
	40	8.3	0.60	275	grit with sand.	clean.	192
	50	8.6	0.50	229	grit with sand.	clean.	--
	60	7.4	0.10	4.6	large gravel with boulders, over clay.	clean.	--
	70	6.8	0.50	19.5	fine grit with gravel; metal; gas bubbles.	clean.	--
J	0	8.0	0.00	0.0	concrete.	clean.	--
	10	8.9	0.00	0.0	fine gray sand; with concrete.	clean.	--
	20	8.6	0.12	62.0	fine gray grit; with concrete.	clean.	--
	30	8.6	0.25	129	fine gray small particles; gas bubbles.	clean.	--
	40	8.0	0.25	129	fine gray small particles.	clean.	--
	50	8.6	0.05	25.8	fine gray small particles; with gravel.	clean.	--
	60	7.4	0.08	41.3	fine gray small particles; with gravel.	clean.	--
	70	6.2	0.05	16.4	fine small particles; with metal.	clean.	--
K	0	7.1	0.00	0.0	concrete.	clean.	--
	10	7.7	0.20	103	gravel; with cobble and concrete.	clean.	--
	20	8.9	0.05	25.8	fine small particles over pellets; with cobble.	clean.	--
	30	8.3	0.05	25.8	gravel; with cobble and (iron ore) pellets.	clean.	--
	40	9.2	0.05	25.8	pellets over clay.	clean.	--
	50	8.9	0.05	25.8	small particles over clay.	clean.	--

Transect	Distance from North shore, m.	Water Depth, m.	Sediment Depth, m.	Sediment Volume, m^3	Sediment Description	Appearance of Plastic Probe	Sediment Sampling Station Number
K	60	8.0	0.20	103	small particles over clay.	clean.	--
	70	8.0	0.12	62.0	small particles over clay; with cobble.	clean.	--
	80	6.2	0.12	62.0	small particles over gravel.	clean.	--
	90	1.2	0.12	55.3	fine gravel.	clean.	--
L	0	8.0	0.12	14.0	pellets.	clean.	--
	10	8.6	0.02	4.7	cobble; with boulders and pellets.	clean.	--
	20	9.2	0.12	28.0	silt over clay.	clean.	--
	30	8.9	0.05	11.7	pellets with cobble, over clay.	clean.	--
	40	8.3	0.05	11.7	small particles over cobble; over clay.	clean.	--
	50	8.6	0.05	11.7	cobble; with gravel and pellets.	clean.	--
	60	7.7	0.25	58.2	coal; with fine gray grit.	clean.	--
	70	4.9	<0.01	2.3	small particles over coarse gravel.	clean.	--
	80	4.3	0.01	2.3	small particles over coarse gravel.	clean.	--
	90	2.5	0.12	61.4	gravel.	clean.	--
Total Sediment Volume				> 14,341			--
--	30	8.0	0.38	--	silty sand over clay; oily.	na	115
--	50	11.5	0.34	--	clay with silty sand.	na	116
--	50	9.5	0.14	--	gravel with silt, over clay.	na	117
--	20	9.5	0.20	--	sand over gravel.	na	33
--	480	4.5	>0.40	--	silt with sand, over clay.	na	52

NOTE: 'na' = no data available.

Appendix II

Station Location and Core Collection Summary

Station:			Replicate Core Lengths, mm.			Sediment Visual Description	Odour
Number	Lat., N	Long., W	A	B	C		
179	46°31'17"	84°22'47"	340	370	370	sand; large coal chunks; coal tar.	coal tar.
183	46°31'16"	84°22'48	432, 342	413, 419	292, 362	black, silty sand; hard-packed.	coal tar (strong).
182	46°31'16"	84°22'47"	420	350	340	sand; gravel; coal particles; coal tar.	--
181	46°31'16"	84°22'46"	310	210, 230	260, 230	silty sand; coal chunks; coal tar; oily.	coal tar (strong).
184	46°31'15"	84°22'47"	380	370	350	sand; coal particles; moderate coal tar.	coal tar (strong).
185	46°31'14"	84°22'46"	340	350	380	silty sand; coal; moderate coal tar.	--
186	46°31'13"	84°22'46"	360	370	420	silty sand; coal; coal tar.	oily.
187	46°31'12"	84°22'45"	380	380	380	silty sand and gravel; oily.	coal tar.
188	46°31'11"	84°22'43"	340	360	380	silty sand; fine coal particles.	--
189	46°31'11"	84°22'43"	360	240	360	silty sand; coal particles.	oily/iron.
190	46°31'10"	84°22'41"	115, 220	170, 230	190, 270	silty sand over clay; macrophytes.	coal tar.
115	46°31'10"	84°22'41"	160	160	160	silty sand over red clay @ 300 mm.; oily.	--
191	46°31'08"	84°22'41"	260	300	380	very soft, fine gray grit.	--
192	46°31'07"	84°22'40"	350	350	340	silty sand with clay patches.	oily.
116	46°31'00"	84°22'34"	320	340	360	mostly clay mixed with silty sand.	--
117	46°30'55"	84°22'29"	100, 110	150, 160	120, 210	sand, gravel & some silt over hard red clay.	--
33	46°30'49"	84°22'27"	150	200	240	silty sand and gravel.	--
52	46°29'49"	84°28'06"	390, 400	385, 400	385, 390	silty sand over soft clay.	--

Appendix III

Qualifications of Sample Sorters, Pickers, and Taxonomists

Taxonomists

Mr Brad Hubley

Education	Bachelor of Science University of Toronto - Entomology 1980-1989

Relevant Experience

1) Royal Ontario Museum (Department of Entomology) (1984, August-September; 1985-present)

* collection manager; responsibilities included the collection, preservation, identification and cataloguing of invertebrate collections
* included several field trips, including a study of aquatic insects associated with springs/seeps and low order streams
* collection and identification of invertebrates throughout southern and northern Ontario.

2) Original Insect Ideas

* sorting, identification, and enumeration of benthic invertebrates for the private sector including, Environmental Applications Group Ltd, Rein Jaagumagi, and Tarandus Associates Limited.

Miscellaneous

* Member of the North American Benthological Society
* Member of the Society for the Preservation of Natural History Collections

Mr Don Stacey

Education — Bachelor of Science
McMaster University - 1988

Relevant Experience

1) Royal Ontario Museum, Department of Invertebrate Zoology

- Research Technician with particular expertise in oligochate taxonomy

2) Consulting

- Identification of freshwater oligochaetes from various lakes and rivers in Quebec for Laboratories SAB, Montreal (1989).
- Identification of freshwater oligochaetes from Lake St. Francois, University of Montreal, Montreal (1990).
- Identification of oligochaetes from lively sludge, Sudbury Sewage Plant, Sudbury, Ontario (1990).
- Identification of oligochaetes from ballast water carried by foreign ocean-going vessels into the Laurentian Great Lakes and upper St. Lawrence River for the Great Lakes Laboratory for Fisheries and Aquatic Sciences, Burlington, Ontario (1991).
- Identification of freshwater oligochaetes from various locations in Ontario for Original Insect Ideas, Toronto, Ontario (1990-1993).

Presented Papers/Posters

"Phenotypic constraint and phylogenetic characters of marine oligochaetes". 27th European Marine Biology Symposium, Dublin, Ireland, 1992. Presented in association with K. A. Coates and B. R. Dilke.

"Oligochaetes of Guyana, Peru, and Ecuador". 13th Annual ROM Research Colloquium, Toronto, Ontario, 1991. Presented in association with K. A. Coates

"Oligochaetes of Guyana, Peru, and Ecuador". Fifth International Symposium on Aquatic Oligochaete Biology, Tallinn, Estonia, 1991. Presented in association with K. A. Coates.

"Systematics and Evolution of Marine Enchytaeidae". Fifth International Symposium on Aquatic Oligochaete Biology, Tallinn, Estonia, 1991. Presented in association with K. A. Coates.

Selected Publications

Coates, K. A. and D. F. Stacey. In Press. Oligochaetes of Guyana, Peru, and Ecuador. Hydrobiologia.

Coates, K. A. and D. F. Stacey. In Press. *Grania* (Oligochaeta, Annelida) of Rottnest Island, Western Australia. Proceedings of the Fifth International Marine Biological Workshop: Flora and Fauna of Rottnest Island, Western Australia. Australian Marine Sciences Association.

Coates, K. A., D. F. Stacey and B. R. Dilke. In Press. Phenotypic Constraint and Phylogenetic Characters of Marine Oligochaetes.

Sorters/Pickers

Ms Margaret Pickles

Education	Bachelor of Science University of Guelph (Minor in Entomology) 1977 - 1982

Relevant Experience

1) Royal Ontario Museum, Department of Entomology (1985-1989)

- duties included the preparation of insect specimens for research collection

2) Contract Work

- Original Insect Ideas - sorting of benthic-invertebrate samples (1990 - 1991)
- Rein Jaagumagi - sorting of benthic-invertebrate samples and calculation of biomass (1985 - 1986)

Appendix IV

Benthic Invertebrate Species Counts

Number per core sample, by station and replicate (A, B, C)

	33A	33B	33C	52A	52B	52C	115A	115B	115C	116A
DIPTERA:										
Ceratopogonidae:										
Bezzia										
Chironomidae:										
Chironominae:		1								
Chironomus (Chironomus)										
Cladotanytarsus					1					
Cryptochironomus										
Glyptotendipes			1							
Hamischia			1							
Phaenopsectra										
Polypedilum			1							
Rheotanytarsus			1							
Orthocladiinae:										1
Epoicoclodius					1	1				
Heterotrissocladius	3	1	2			1				
Nanocladius			3							
Tanypodinae:										
Apsectrotanypus										
Procladius									1	
EPHEMEROPTERA:										
Ephemeridae:										
Ephemera		1								
Hexagenia					1					
GASTROPODA:										
Physidae:										
Physa gyrina										
Valvatidae:										
Valvata	1									
PELECYPODA:										
Sphaeriidae:										
Pisidium		2	6							
AMPHIPODA:										
Gammaridae:										
Gammarus				1	1	7				
ISOPODA:										
Asellidae:										
Caecidotea					4	9				
OLIGOCHAETA:										
Tubificidae:										
Imm. tubificid w/ bifid chetae										
Imm. tubificid w/ simple chetae						3				
Spirosperma ferox	2		8			2				
Quistadrilus multisetosus			1							
Nadidae:	3	4								
Nais barbata		3								
Nais	1									
Nais/Dero										

	116B	116C	117A	117B	117C	179A	179B	179C	181A	181B
DIPTERA:										
Ceratopogonidae:										
Bezzia										
Chironomidae:										
Chironominae:										
Chironomus (Chironomus)								2		
Cladotanytarsus										
Cryptochironomus			1							
Glyptotendipes										
Harnischia										
Phaenopsectra								1		
Polypedilum										
Rheotanytarsus				1	1					
Orthocladiinae:				5	6		1			
Epoicoclodius			1							
Heterotrissocladius			1							
Nanocladius			1							
Tanypodinae:										
Apsectrotanypus					2					
Procladius			1	2	3					
EPHEMEROPTERA:										
Ephemeridae:										
Ephemera										
Hexagenia										
GASTROPODA:										
Physidae:										
Physa gyrina										
Valvatidae:										
Valvata										
PELECYPODA:										
Sphaeriidae:										
Pisidium										
AMPHIPODA:										
Gammaridae:										
Gammarus										
ISOPODA:										
Asellidae:										
Caecidotea										
OLIGOCHAETA:										
Tubificidae:										
Imm. tubificid w/ bifid chetae										
Imm. tubificid w/ simple chetae										
Spirosperma ferox										
Quistadrilus multisetosus										
Nadidae:										
Nais barbata										
Nais										
Nais/Dero									1	

	181C	182A	182B	182C	183A1	183A2	183B1	183B2	183C1	183C2
DIPTERA:										
Ceratopogonidae:										
Bezzia										
Chironomidae:										
Chironominae:										
Chironomus (Chironomus)										
Cladotanytarsus										
Cryptochironomus										
Glyptotendipes										
Hamischia										
Phaenopsectra										
Polypedilum										
Rheotanytarsus										
Orthocladiinae:					2		2	2		
Epoicoclodius										
Heterotrissocladius										
Nanocladius										
Tanypodinae:										
Apsectrotanypus										
Procladius						2		1		
EPHEMEROPTERA:										
Ephemeridae:										
Ephemera										
Hexagenia										
GASTROPODA:										
Physidae:										
Physa gyrina									1	
Valvatidae:										
Valvata										
PELECYPODA:										
Sphaeriidae:										
Pisidium										
AMPHIPODA:										
Gammaridae:										
Gammarus										
ISOPODA:										
Asellidae:										
Caecidotea										
OLIGOCHAETA:										
Tubificidae:										
Imm. tubificid w/ bifid chetae									3	
Imm. tubificid w/ simple chetae										
Spirosperma ferox										
Quistadrilus multisetosus										
Nadidae:								1		
Nais barbata										
Nais								1		
Nais/Dero										

	184A	184B	184C	185A	185B	185C	186A	186B	186C	187A
DIPTERA:										
Ceratopogonidae:										
Bezzia		1								
Chironomidae:										
Chironominae:										
Chironomus (Chironomus)										
Cladotanytarsus										
Cryptochironomus										
Glyptotendipes										
Harnischia										
Phaenopsectra										
Polypedilum										
Rheotanytarsus										
Orthocladiinae:										
Epoicoclodius										
Heterotrissocladius										
Nanocladius										
Tanypodinae:										
Apsectrotanypus										
Procladius										
EPHEMEROPTERA:										
Ephemeridae:										
Ephemera										
Hexagenia										
GASTROPODA:										
Physidae:										
Physa gyrina										
Valvatidae:										
Valvata										
PELECYPODA:										
Sphaeriidae:										
Pisidium										
AMPHIPODA:										
Gammaridae:										
Gammarus										
ISOPODA:										
Asellidae:										
Caecidotea										
OLIGOCHAETA:										
Tubificidae:										
Imm. tubificid w/ bifid chetae					1					
Imm. tubificid w/ simple chetae										
Spirosperma ferox										
Quistadrilus multisetosus										
Nadidae:										
Nais barbata										
Nais										
Nais/Dero										

	187B	187C	188A	188B	188C	189A	189B	189C	190A	190B
DIPTERA:										
Ceratopogonidae:										
Bezzia										
Chironomidae:										
Chironominae:										
Chironomus (Chironomus)										
Cladotanytarsus										
Cryptochironomus										
Glyptotendipes										
Hamischia										
Phaenopsectra										
Polypedilum										
Rheotanytarsus										
Orthocladiinae:										
Epoicoclodius										
Heterotrissocladius										
Nanocladius										
Tanypodinae:										
Apsectrotanypus										
Procladius				1						
EPHEMEROPTERA:										
Ephemeridae:										
Ephemera										
Hexagenia										
GASTROPODA:										
Physidae:										
Physa gyrina										
Valvatidae:										
Valvata										
PELECYPODA:										
Sphaeriidae:										
Pisidium										
AMPHIPODA:										
Gammaridae:										
Gammarus										
ISOPODA:										
Asellidae:										
Caecidotea										
OLIGOCHAETA:										
Tubificidae:										
Imm. tubificid w/ bifid chetae										
Imm. tubificid w/ simple chetae										
Spirosperma ferox										
Quistadrilus multisetosus										
Nadidae:										
Nais barbata										
Nais										
Nais/Dero										

	190C	191A	191B	191C	192A	192B	192C
DIPTERA:							
Ceratopogonidae:							
Bezzia							
Chironomidae:							
Chironominae:							
Chironomus (Chironomus)							
Cladotanytarsus							
Cryptochironomus							
Glyptotendipes							
Harnischia							
Phaenopsectra							
Polypedilum							
Rheotanytarsus							
Orthocladiinae:							
Epoicoclodius							
Heterotrissocladius							
Nanocladius							
Tanypodinae:							
Apsectrotanypus							
Procladius							
EPHEMEROPTERA:							
Ephemeridae:							
Ephemera							
Hexagenia							
GASTROPODA:							
Physidae:							
Physa gyrina							
Valvatidae:							
Valvata							
PELECYPODA:							
Sphaeriidae:							
Pisidium							
AMPHIPODA:							
Gammaridae:							
Gammarus							
ISOPODA:							
Asellidae:							
Caecidotea			1				
OLIGOCHAETA:							
Tubificidae:							
Imm. tubificid w/ bifid chetae							
Imm. tubificid w/ simple chetae							
Spirosperma ferox				1			
Quistadrilus multisetosus							
Nadidae:			2	2			
Nais barbata							
Nais							
Nais/Dero							

Appendix V

Benthic Invertebrate Species Abundances for Individual Samples

Number.m^{-2}, by station and replicates (A, B, C)

Species abundances (number.m^{-2}) for each core were calculated using multiplication factors which adjusted the individual species counts, based on the total volume of each core replicate and the surface area of the core tube.

Station	33A	33B	33C	52A	52B	52C	115A	115B	115C	116A
Multiplication Factor	100.0	133.4	160.0	260.1	256.7	256.7	106.7	106.7	106.7	213.4
DIPTERA:										
Ceratopogonidae:										
Bezzia sp.										
Chironomidae:										
Chironominae:		133.4								
Chironomus (Chironomus) sp.										
Cladotanytarsus sp.					256.7					
Cryptochironomus sp.										
Glyptotendipes sp.			160.0							
Harnischia sp.			160.0							
Phaenopsectra sp.										
Polypedilum sp.			160.0							
Rheotanytarsus sp.			160.0							
Orthocladiinae:										213.4
Epoicoclodius sp.					256.7	256.7				
Heterotrissocladius sp.	300.0	133.4	320.0			256.7				
Nanocladius sp.			480.0							
Tanypodinae:										
Apsectrotanypus sp.										
Procladius sp.									106.7	
EPHEMEROPTERA:										
Ephemeridae:										
Ephemera sp.		133.4								
Hexagenia sp.					256.7					
GASTROPODA:										
Physidae:										
Physa gyrina										
Valvatidae:										
Valvata sp.	100.0									
PELECYPODA:										
Sphaeriidae:										
Pisidium sp.		266.8	960.0							
AMPHIPODA:										
Gammaridae:										
Gammarus sp.				260.1	256.7	1796.9				
ISOPODA:										
Asellidae:										
Caecidotea sp.					1026.8	2310.3				
OLIGOCHAETA:										
Tubificidae:										
Imm. tubificid w/ bifid chetae										
Imm. tubificid w/ simple chetae						770.1				
Spirosperma ferox	200.0		1280.0			513.4				
Quistadrilus multisetosus			160.0							
Nadidae:	300.0	533.6								
Nais barbata		400.2								
Nais sp.	100.0									
Nais/Dero sp.										

Station	116B	116C	117A	117B	117C	179A	179B	179C	181A	181B
Multiplication Factor	226.7	240.1	66.7	100.0	80.0	226.7	246.7	246.7	206.7	140.0
DIPTERA:										
Ceratopogonidae:										
Bezzia sp.										
Chironomidae:										
Chironominae:										
Chironomus (Chironomus) sp.								493.4		
Cladotanytarsus sp.										
Cryptochironomus sp.			66.7							
Glyptotendipes sp.										
Harnischia sp.										
Phaenopsectra sp.								246.7		
Polypedilum sp.										
Rheotanytarsus sp.				100.0	80.0					
Orthocladiinae:				500.0	480.0		246.7			
Epoicoclodius sp.			66.7							
Heterotrissocladius sp.			66.7							
Nanocladius sp.			66.7							
Tanypodinae:										
Apsectrotanypus sp.					160.0					
Procladius sp.			66.7	200.0	240.0					
EPHEMEROPTERA:										
Ephemeridae:										
Ephemera sp.										
Hexagenia sp.										
GASTROPODA:										
Physidae:										
Physa gyrina										
Valvatidae:										
Valvata sp.										
PELECYPODA:										
Sphaeriidae:										
Pisidium sp.										
AMPHIPODA:										
Gammaridae:										
Gammarus sp.										
ISOPODA:										
Asellidae:										
Caecidotea sp.										
OLIGOCHAETA:										
Tubificidae:										
Imm. tubificid w/ bifid chetae										
Imm. tubificid w/ simple chetae										
Spirosperma ferox										
Quistadrilus multisetosus										
Nadidae:										
Nais barbata										
Nais sp.										
Nais/Dero sp.									206.7	

Station	181C	182A	182B	182C	183A1	183A2	183B1	183B2	183C1	183C2
Multiplication Factor	173.4	280.1	233.4	226.7	288.1	228.1	275.4	279.4	194.7	241.3
DIPTERA:										
Ceratopogonidae:										
Bezzia sp.										
Chironomidae:										
Chironominae:										
Chironomus (Chironomus) sp.										
Cladotanytarsus sp.										
Cryptochironomus sp.										
Glyptotendipes sp.										
Harnischia sp.										
Phaenopsectra sp.										
Polypedilum sp.										
Rheotanytarsus sp.										
Orthocladiinae:					576.2			558.8		
Epoicoclodius sp.										
Heterotrissocladius sp.										
Nanocladius sp.										
Tanypodinae:										
Apsectrotanypus sp.										
Procladius sp.						456.2		279.4		
EPHEMEROPTERA:										
Ephemeridae:										
Ephemera sp.										
Hexagenia sp.										
GASTROPODA:										
Physidae:										
Physa gyrina									194.7	
Valvatidae:										
Valvata sp.										
PELECYPODA:										
Sphaeriidae:										
Pisidium sp.										
AMPHIPODA:										
Gammaridae:										
Gammarus sp.										
ISOPODA:										
Asellidae:										
Caecidotea sp.										
OLIGOCHAETA:										
Tubificidae:										
Imm. tubificid w/ bifid chetae									584.1	
Imm. tubificid w/ simple chetae										
Spirosperma ferox										
Quistadrilus multisetosus										
Nadidae:								279.4		
Nais barbata										
Nais sp.								279.4		
Nais/Dero sp.										

Station	184A	184B	184C	185A	185B	185C	186A	186B	186C	187A
Multiplication Factor	253.4	246.7	233.4	226.7	233.4	253.4	240.1	246.7	280.1	253.4
DIPTERA:										
Ceratopogonidae:										
Bezzia sp.		246.7								
Chironomidae:										
Chironominae:										
Chironomus (Chironomus) sp.										
Cladotanytarsus sp.										
Cryptochironomus sp.										
Glyptotendipes sp.										
Harnischia sp.										
Phaenopsectra sp.										
Polypedilum sp.										
Rheotanytarsus sp.										
Orthocladiinae:										
Epoicoclodius sp.										
Heterotrissocladius sp.										
Nanocladius sp.										
Tanypodinae:										
Apsectrotanypus sp.										
Procladius sp.										
EPHEMEROPTERA:										
Ephemeridae:										
Ephemera sp.										
Hexagenia sp.										
GASTROPODA:										
Physidae:										
Physa gyrina										
Valvatidae:										
Valvata sp.										
PELECYPODA:										
Sphaeriidae:										
Pisidium sp.										
AMPHIPODA:										
Gammaridae:										
Gammarus sp.										
ISOPODA:										
Asellidae:										
Caecidotea sp.										
OLIGOCHAETA:										
Tubificidae:										
Imm. tubificid w/ bifid chetae					233.4					
Imm. tubificid w/ simple chetae										
Spirosperma ferox										
Quistadrilus multisetosus										
Nadidae:										
Nais barbata										
Nais sp.										
Nais/Dero sp.										

Station	187B	187C	188A	188B	188C	189A	189B	189C	190A	190B
Multiplication Factor	253.4	253.4	226.7	240.1	253.4	240.1	160.0	240.1	76.7	113.4
DIPTERA:										
Ceratopogonidae:										
Bezzia sp.										
Chironomidae:										
Chironominae:										
Chironomus (Chironomus) sp.										
Cladotanytarsus sp.										
Cryptochironomus sp.										
Glyptotendipes sp.										
Hamischia sp.										
Phaenopsectra sp.										
Polypedilum sp.										
Rheotanytarsus sp.										
Orthocladiinae:										
Epoicoclodius sp.										
Heterotrissocladius sp.										
Nanocladius sp.										
Tanypodinae:										
Apsectrotanypus sp.										
Procladius sp.				240.1						
EPHEMEROPTERA:										
Ephemeridae:										
Ephemera sp.										
Hexagenia sp.										
GASTROPODA:										
Physidae:										
Physa gyrina										
Valvatidae:										
Valvata sp.										
PELECYPODA:										
Sphaeriidae:										
Pisidium sp.										
AMPHIPODA:										
Gammaridae:										
Gammarus sp.										
ISOPODA:										
Asellidae:										
Caecidotea sp.										
OLIGOCHAETA:										
Tubificidae:										
Imm. tubificid w/ bifid chetae										
Imm. tubificid w/ simple chetae										
Spirosperma ferox										
Quistadrilus multisetosus										
Nadidae:										
Nais barbata										
Nais sp.										
Nais/Dero sp.										

Station	190C	191A	191B	191C	192A	192B	192C
Multiplication Factor	126.7	173.4	200.0	253.4	233.4	233.4	226.7
DIPTERA:							
Ceratopogonidae:							
Bezzia sp.							
Chironomidae:							
Chironominae:							
Chironomus (Chironomus) sp.							
Cladotanytarsus sp.							
Cryptochironomus sp.							
Glyptotendipes sp.							
Harnischia sp.							
Phaenopsectra sp.							
Polypedilum sp.							
Rheotanytarsus sp.							
Orthocladiinae:							
Epoicoclodius sp.							
Heterotrissocladius sp.							
Nanocladius sp.							
Tanypodinae:							
Apsectrotanypus sp.							
Procladius sp.							
EPHEMEROPTERA:							
Ephemeridae:							
Ephemera sp.							
Hexagenia sp.							
GASTROPODA:							
Physidae:							
Physa gyrina							
Valvatidae:							
Valvata sp.							
PELECYPODA:							
Sphaeriidae:							
Pisidium sp.							
AMPHIPODA:							
Gammaridae:							
Gammarus sp.							
ISOPODA:							
Asellidae:							
Caecidotea sp.			200.0				
OLIGOCHAETA:							
Tubificidae:							
Imm. tubificid w/ bifid chetae							
Imm. tubificid w/ simple chetae							
Spirosperma ferox				253.4			
Quistadrilus multisetosus							
Nadidae:			400.0	506.8			
Nais barbata							
Nais sp.							
Nais/Dero sp.							